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(UNCLASSIFIED TITLE)

PROPELLANT HANDBOOK

PAUL J. VON DOEHRN, 1/LT, USAF

JANUARY 1966

**AIR FORCE ROCKET PROPULSION LABORATORY
RESEARCH AND TECHNOLOGY DIVISION
AIR FORCE SYSTEMS COMMAND
UNITED STATES AIR FORCE
EDWARDS, CALIFORNIA**

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January 1966

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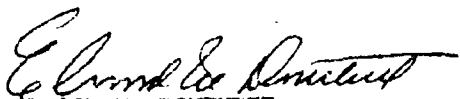
FOREWORD

This report was prepared under task number 314802 by 1/Lt Paul J. von Doehren, Air Force Rocket Propulsion Laboratory (RPCL). The general format of this report is based in part on a compilation (not published as a formal report) by 1/Lt William H. Summers, AFRPL (RPCL) prepared in May 1963. The densities and heats of formation of solid propellant components were abstracted from an unpublished compilation by Curtis C. Selph, AFRPL (RPCL). Acknowledgement of assistance received in the assembly and verification of the data presented in this report is extended to the Liquid Propellant, Solid Propellant, and Chemical and Materials Branches of the Propellant Division, AFRPL.

Classified information has been extracted from documents listed under "References" marked with an asterisk (*).

This technical report has been reviewed and is approved.


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A compilation of data on both liquid and solid propellants is presented with emphasis on liquids. Physical properties of liquids include: boiling point, freezing point, density, heat of formation, vapor pressure, critical properties, heat of vaporization, viscosity and specific heat. A discussion of the preparation method, toxicity, sensitivity, compatibility and availability of liquid propellants is also given. Property data on solid propellant components consists of densities and heats of formation. The results of theoretical calculations on the performance of both liquids and solids is presented and includes, when available and applicable, the maximum specific impulse, characteristic exhaust velocity, chamber temperature, mixture ratio, bulk density, maximum density impulse and mixture ratio, vacuum specific impulse and area ratio.

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I. INTRODUCTION

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INTRODUCTION

This handbook is intended as a source of general information concerning rocket propellant properties and theoretical performance. The inclusion (or exclusion) of a propellant or propellant combination does not necessarily reflect the current Air Force interest in propellant systems. Some general comments concerning the treatment and compilation of data for this handbook are outlined in the following paragraphs.

Liquid Propellant Properties

The sections on liquid propellant properties give physical property, preparation, toxicity, sensitivity, compatibility and availability data for rocket propellants. Additional information in these areas is available in many cases by referring to the original source. When several different values of a physical property were found, in general, either the one appearing most frequently or the latest value was selected. If a value is in question or its precision critical then it would be advisable to refer to the original reference.

Propellant property information will be available after June 1966 from Contract AF 04(611)-10546, "Engineering Property Data on Rocket Propellants". The handbook published under this contract, when available, should be consulted for current property information.

Liquid Propellant Theoretical Performance

The latest JANAF propellant data was used in calculating theoretical propellant performance on the AFRPL (IBM 7040) computer program. Curves of specific impulse, chamber temperature, characteristic exhaust velocity, etc. vs percent oxidizer were plotted by hand and the appropriate values extracted from these curves. The performance values are intended to provide a rough means of determining the relative merit of propellant combinations.

No allowance was made for the gelling agent or emulsion external phase when calculating the theoretical performance of metal suspension systems. The data for these systems can therefore be considered an upper limit of performance since the additives to produce gels or emulsions have a relatively low performance level. The amount of degradation in performance will vary according to the amount and type of gelling agent or external phase used.

Solid Propellant Properties

This section gives densities and heats of formation for various fuels, oxidizers, binders and additives. This information was originally assembled as a data source for in-house theoretical performance calculations.

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Solid Propellant Theoretical Performance

The theoretical performance data for selected solid propellant compositions are listed according to the fuel and oxidizer used. The information was assembled from AFRPL calculations and available literature and is intended to give an overall view of the theoretical performance available from selected solid propellant compositions.

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II. LIQUID PROPELLANT PROPERTIES
(Fuels)

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HYDRAZINE

Formula: N_2H_4

Physical Properties:

Boiling Point:	113°C	(1)
Freezing Point:	1.4°C	(1)
Density:	1.008 g/cc @ 20°C	(1)
Heat of Formation:	+12.05 Kcal/mole @ 298.15°K	(2)
Vapor Pressure:	0.204 psia @ 20°C	(1)
	2.806 psia @ 70°C	(1)
Critical Temperature:	380°C	(1)
Critical Pressure:	145 atm	(1)
Heat of Vaporization:	10.7 Kcal/mole @ 25.0°C	(1)
Viscosity:	0.9736 cp @ 20°C	(1)
Specific Heat:	0.738 cal/gm°C @ 25°C	(1)

Preparation: Hydrazine is manufactured by the Raschig process, which involves the oxidation of ammonia to chloramine, either indirectly with aqueous sodium hypochlorite or directly with chlorine, and subsequent reaction of chloramine with excess ammonia. (9)

Toxicity: If spilled on the skin or in the eyes, liquid hydrazine can cause severe local damage or burns and can cause dermatitis. In addition, it can penetrate skin to cause systemic effects similar to those produced when the compound is swallowed or inhaled. If inhaled, the vapor causes local and systemic effects. Repeated exposure may cause toxic damage to the liver and kidney, as well as anemia. The threshold limit is 1 ppm (1.3 mg/cu m). (7)

Sensitivity: Hydrazine is a stable liquid under the extremes of heat and cold expected in long-term storage. It will freeze, but contracts, so no vessel damage results. Freezing does not affect the chemical properties of hydrazine. Thermal decomposition begins at about 320°F, but if hydrazine is permitted to remain in contact with catalysts such as copper, molybdenum or iron oxide, decomposition may occur at room temperature. Liquid hydrazine is stable to shock. Hydrazine vapor can be exploded by a spark or flame if it is within the flammable limits. (7)

Compatibility: The following metals may be used with hydrazine: stainless steel (303, 304, 316, service limited to 160°F, 321 and 347), nickel, aluminum (3003, 5052, 5154, 1060 and 6061). Non-metals include Teflon, high-density polyethylene and unplasticized Kel-F. Thus far, a completely satisfactory lubricant has not been developed. The Quigley Company's "Q-Seal" is being used with fair results. (7)

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Availability: Anhydrous hydrazine is readily available. Present cost: \$3.72 per pound.

Remarks: For additional information consult references (1) and (12).
Military Specification, Mil-P-26536, Propellant, Hydrazine

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MONOMETHYL HYDRAZINE (MMH)

Formula: $(CH_3)HNNH_2$

Physical Properties:

Boiling Point:	87.5°C	(1)
Freezing Point:	-52.4°C	(1)
Density:	0.8743 @ 25°C	(1)
Heat of Formation:	12.7 Kcal/mole	(1)
Vapor Pressure:	49.63 mm Hg @ 25°C	(1)
	171 mm Hg @ 50°C	(1)
Critical Temperature:	---	
Critical Pressure:	---	
Heat of Vaporization:	9648 cal/mole @ 25°C	(1)
Viscosity:	0.893 centistokes	(1)
Specific Heat:	32.25 cal/mole°K @ 25°C	(1)

Preparation: MMH may be produced by a modified Raschig process; methylamine is substituted for ammonia in the reactor with chloramine (see hydrazine). (9)

Toxicity: Liquid MMH in contact with skin or eyes can cause local damage resembling burns; in addition, it can penetrate skin to cause systemic effects. Inhalation of the vapor causes from slight to severe irritation of the respiratory passages, as well as systemic effects. Evidence on the effects of chronic toxicity is lacking. No threshold limit value for MMH has been recommended; consideration of data on its acute toxicity and analogy with UDMH and hydrazine suggest that the proper value should be below 0.5 ppm. (7)

Sensitivity: MMH is a stable liquid under the extremes of heat and cold expected in long-term storage. It will freeze, but because it contracts on freezing there is no damage to storage vessels. It is stable up to its atmospheric boiling point if kept from contact with oxygen. Catalysts such as rust, copper or copper alloys can cause it to decompose and finally to ignite. MMH is stable to friction or impact. Vapors of MMH within flammable limits can be exploded by a spark or flame. (7)

Compatibility: The acceptability of materials in contact with MMH depends upon the specific application for which they are intended. The requirements for long-term storage differ considerably from those pertaining to a once-used piece of equipment. If the properties (or other aspects) of a material indicate the desirability of its use, it would be well to evaluate this material with MMH under the conditions expected during operation before removing it from consideration. Because of MMH's solvent properties, no completely suitable lubricant has been found. (7)

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Availability: Readily available. Present cost: \$2.47 bulk pound.
Projected cost for larger scale production is \$0.60 to \$1.25/lb.
(9)

Military Specification, Mil-P-27404, Propellant, Monomethyl Hydrazine

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UNSYMMETRICAL DIMETHYL HYDRAZINE (UDMH)

Formula: $(CH_3)_2NNH_2$

Physical Properties:

Boiling Point:	63°C	(1)
Freezing Point:	-57.21°C	(1)
Density:	0.7861 @ 25°C	(1)
Heat of Formation:	+11.9 Kcal/mole @ 298.15°K	(2)
Vapor Pressure:	2.3668 @ 25°C	(1)
Critical Temperature:	249°C	(1)
Critical Pressure:	60 atm	(1)
Heat of Vaporization:	8.366 Kcal/mole @ 25°C	(1)
Viscosity:	0.509 cp @ 25°C	(1)
Specific Heat:	0.6526 cal/gm°C @ 25°C	(1)

Preparation: UDMH can be produced commercially by nitrosation of dimethylamine, to N-nitrosodimethylamine, followed by reduction of the intermediate to UDMH and subsequent purification. UDMH can be prepared, also, by a modification of the Raschig process, in which the chloramine intermediate is reacted with dimethylamine rather than with ammonia. (9)

Toxicity: UDMH is mildly irritating to skin and eyes and can penetrate skin to cause systemic toxicity, but it is not as dangerous in this regard as hydrazine. The vapor causes eye and respiratory irritation as well as systemic effects. The results of repeated exposure may be chronic poisoning, characterized by anemia. The threshold limit of UDMH is 0.5 ppm. (7)

Sensitivity: UDMH is not shock sensitive. It shows good thermal stability, even up to its critical temperature, 480°F. The spontaneous decomposition temperature of UDMH in an atmosphere of nitrogen or helium has been determined to be 740°F to 750°F at 1 atmosphere, but decomposition does not become explosive up to at least 1112°F. (7)

Compatibility: UDMH is compatible with most common metals and may be handled in containers made of those materials under a wide variety of conditions. There is no known limitation on use of UDMH with nickel, Monel or types 303, 304, 316, 321 and 347 stainless steel. It has been noted that aluminum is attacked to some extent by dilute aqueous solutions of UDMH. UDMH typically contains about 0.1% water. The use of copper and high copper alloys is prohibited in UDMH transfer and storage equipment. In view of the variable nature of the service in which nonmetals may be used, it is undesirable to be specific regarding their performance. Apiezon L and Reddy Lube 200, the best lubricants currently known, are satisfactory for many applications. (7)

Availability: Readily available at \$.56 a bulk pound.

Military Specification, Mil-P-25604, Propellant, uns Dimethylhydrazine

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50/50 UDMH/ N_2C_4 (AEROZINE 50)

Composition: 51% N_2H_4
49% $(\text{CH}_3)_2\text{NNH}_2$

Physical Properties:

Boiling Point:	70.1°C	(10)
Freezing Point:	17.3°C	(10)
Density:	0.899 g/cc @ 25°C	(10)
Heat of Formation:	12.251 Kcal/mole @ 25°C (calc)	(10)
Vapor Pressure:	142.1 mm Hg @ 25°C	(10)
Critical Temperature:	334°C (calc)	(10)
Critical Pressure:	115.4 atm (calc)	(10)
Heat of Vaporization:	236.7 cal/gm (calc)	(10)
Viscosity:	0.91 centistokes @ 25°C	(10)
Specific Heat	0.694 cal/gm°C	(10)

Preparation: 50/50 is a mixture of commercial concentrated hydrazine and commercial UDMH in approximately equal portions by weight.

Typical composition: N_2H_4 51.0%, UDMH 48.2%, H_2O 0.5% and other impurities 0.3%. (10)

Toxicity: UDMH constitutes 90% of the vapor. It may be absorbed through the intact skin, by inhalation of fumes and by ingestion. 50/50 can cause irritation of the mucous membranes of the eyes, respiratory passages, lungs and gastrointestinal tract. Immediate symptoms of inhalation are chest pain, coughing, wheezing, nausea and vomiting. If large amounts have been inhaled, pulmonary edema may occur. Allowable concentration, 0.5 ppm. (11)

Sensitivity: Both constituents react with air so that 50/50 should be kept under a nitrogen blanket. (See UDMH and Hydrazine) (10)

Compatibility: Compatible with: stainless steel, aluminum, titanium and nickel alloys, Diamine Nylons, Teflon, certain butyl-rubber compounds, graphite and some silicone-base greases. Alloys of copper may be used only in specific applications upon advice of a metallurgist. Alloys of magnesium and zinc are not recommended. (10)

Availability: Readily available at \$.66/lb.

Remarks: For further information see references (10) and (11).

*Based on the composite formula $\text{C}_{0.678}\text{H}_{5.356}\text{N}_{2.0}$

Military Specification, Mil-P-27402, Propellant, Hydrazine - uns-Dimethylhydrazine (50% N_2H_4 - 50% UDMH)

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RP-1

Formula: $\text{CH}_{1.9532}$

Physical Properties:

Boiling Point:	177 to 274°C	(9)
Freezing Point:	-40°C (maximum)	(9)
Density:	0.801 to 0.815 g/cc @ 20°C	(Mil Spec)
Heat of Formation:	-5.76 Kcal/mole	(3)
Vapor Pressure:	0.36 psia @ 66°C	(1)
Critical Temperature:	---	
Critical Pressure:	---	
Heat of Vaporization:	---	
Viscosity:	16.5 centistokes @ -34.4°C	(Mil Spec)
Specific Heat:	---	

Preparation: RP-1 is a straight-run kerosene fraction, which is subjected to further treatment, i.e. acid washing, sulfur dioxide extraction. Unsaturated substances which polymerize in storage are removed, as are sulfur-containing hydrocarbons. The kerosene must be obtained from crudes with a high naphthene content. (9)

Toxicity: RP-1 produces moderate skin irritation and after more than momentary contact can cause scaling and fissuring of the skin. The main danger comes from accidental swallowing; while not especially toxic by this route, gasping while swallowing or aspiration from improperly induced vomiting can introduce the liquid into the lungs, and pulmonary edema may ensue.

Sensitivity: RP-1 is chemically stable and insensitive to shock. It shows good thermal stability over a wide range of ambient storage temperatures, but exposure to high temperatures accelerates the formation of gum and sediment.

Compatibility: Steel should be used with RP-1. Copper alloys (with brass, bronze or beryllium) should not be used where they will be continually in contact with the fuel, as they promote gum formation. The following non-metals may be used: vinyls, Teflon, Kel-F, polyethylene, polyamides, neoprene, Buna N and asbestos, cork and paper gasket materials designed for this service. Graphite-base, molybdenum-disulfide and some silicone and fluorocarbon lubricants may be used.

Availability: RP-1 is readily available at \$.15 a pound.

Military Specification, Mil-P-25576, Rocket Fuel RP-1

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HYDROGEN

Formula: H_2

Physical Properties:

Boiling Point:	20.39°K	(1)
Freezing Point:	-259.14°C	(1)
Density:	0.0710 g/cc @ 20.39°K	(1)
Heat of Formation:	-1.887 Kcal/mole @ 20.4°K	(1)
Vapor Pressure:	---	
Critical Temperature:	33.26°K	(1)
Critical Pressure:	12.8 atm	(1)
Heat of Vaporization:	0.2193 Kcal/mole @ 20.39°C	(1)
Viscosity:	140.5 x 10 ⁻⁶ poise @ 20.39°K	(1)
Specific Heat	1.45 cal/gm @ -253°C	(1)

Preparation: Hydrogen is produced from by-product hydrogen from petroleum refining and the partial oxidation of fuel oil. The gaseous hydrogen is purified to 99.999⁺ per cent, and then liquified in the presence of paramagnetic metallic oxides. It is composed of 99.79 per cent parahydrogen. (9)

Toxicity: Hydrogen is not toxic in the usual sense. Serious burns can result when skin or other tissues come into contact with the liquid or with pipes and valves containing the liquid because of its temperature. The gas can exclude oxygen and cause asphyxiation. Cold hydrogen vapors can also "burn" the skin. (7)

Sensitivity: Liquid hydrogen is chemically stable. Because of its low boiling point, it is physically stable only when stored under suitable conditions. (7)

Compatibility: The ability of materials to retain satisfactory properties and withstand stresses caused by large temperature changes is of prime importance. Suitable metals include: stainless steel (300 and other austenitic series), copper, bronze, brass, Monel, aluminum and Ever⁺. Non-metals include: Dacron, Teflon, Kel-F, Asbestos impregnated with Teflon, Mylar films and Nylon. Lubricants are generally not practical in the presence of liquid hydrogen, for they solidify and become brittle at the liquid's temperature. Vacuum grease is satisfactory as a sealant with "O" rings. (7)

Availability: Readily available, present cost is \$.85 per pound. Larger scale production is expected to reduce the cost to \$.50 per pound. (9)

Military Specification, Mil-P-27201, Propellant, Hydrogen

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AMMONIA

Formula: NH_3

Physical Properties:

Boiling Point:	-33.4°C	(1)
Freezing Point:	-77.7°C	(1)
Density:	0.6920 g/cc @ -33.4°C	(1)
Heat of Formation:	-17.14 Kcal/mole	(1)
Vapor Pressure:	---	
Critical Temperature:	132.4°C	(1)
Critical Pressure:	111.3 atm	(1)
Heat of Vaporization:	4805 cal/mole @ 25°C	(1)
Viscosity:	0.266 cp @ -33.5°C	(1)
Specific Heat:	18.12 cal/mole°C @ -33.1°C	(1)

Preparation: Ammonia is produced by the Haber-Bosch process, in which the elements, nitrogen and hydrogen, are united at a temperature of 500 to 600°C and a pressure of approximately 200 atm in the presence of a promoted iron catalyst. (9)

Toxicity: Liquid ammonia, because of its low temperature and caustic properties, can cause damage to the skin and eyes. The vapor is irritating to the skin, eyes and respiratory tract. The threshold limit value is 50 ppm. The odor is usually detectable below the limit. Inhalation of concentrations around 2500 ppm are hazardous to life in one-half hour. (7)

Sensitivity: Ammonia is very stable and is not shock sensitive. It is thermally stable at temperatures as high as 480°C, above which dissociation to nitrogen and hydrogen begins. (7)

Compatibility: Anhydrous ammonia (liquid) and ammonia vapor may be used with nickel and stainless steel (300 and 400 series) at all temperatures and with steel at ambient temperatures. Teflon, Kel-F and pure asbestos may be used. Fluorolubes or the perfluorocarbons may be used as lubricants. Other materials which have been tested and approved for ammonia service may be used. (7)

Availability: Anhydrous ammonia is readily available at \$.05 a pound.

Military Specification, Mil-P-27406 (Not Approved)

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PENTABORANE

Formula: B_5H_9

Physical Properties:

Boiling Point:	$-46.5^{\circ}C$	(16)
Freezing Point:	$60.0^{\circ}C$	(16)
Density:	0.618 g/cc @ $25^{\circ}C$	(16)
Heat of Formation:	$+7.74$ Kcal/mole @ $298.15^{\circ}K$	(2)
Vapor Pressure:	6/7 mm Hg @ $0.0^{\circ}C$	(16)
	4.0 psia @ $25^{\circ}C$	(16)
Critical Temperature:	---	
Critical Pressure:	---	
Heat of Vaporization:	7.28 Kcal/mole @ $25^{\circ}C$	(16)
Viscosity:	0.499 centistokes @ $25^{\circ}C$	(16)
Specific Heat:	36.2 cal/mole $^{\circ}C$ @ $25^{\circ}C$	(16)

Preparation: Pentaborane is produced by the pyrolysis of diborane; the conversion is not a clean cut reaction. The resulting products are dependent upon the pyrolysis temperature. At $180^{\circ}C$ the pre-dominant products are B_5H_9 and $B_{10}H_{14}$. (9)

Toxicity: Inhalation is the most common means by which pentaborane enters the body. In most cases of poisoning, there will be signs and symptoms of the involvement of the central and possibly the peripheral nervous systems. The onset of symptoms may be delayed several hours. Exposure may cause abnormalities for several days despite outward appearances and recovery may not be complete for several weeks. The threshold limit is 0.005 ppm (0.01 mg/cu m). (7)

Sensitivity: In the absence of air or contaminants, pentaborane is stable at room temperature. It decomposes at $302^{\circ}F$, but not explosively. Small amounts of oxygen or moisture will cause solid deposits to form in pentaborane. Metal oxides also affect its stability. (7) Pentaborane, by itself, is insensitive to shock, however, it may form shock sensitive compounds with most chlorinated organic compounds having more than one chlorine per carbon or containing carbonyl groups. (16)

Compatibility: The following metals are approved for use: aluminum (5052-S, 6061-T6, 7075-T6, 2024-T3, 3003-H14, 354-T6) (These alloys may be anodized), stainless steel (18-8 series), low carbon steels, K-Monel, Monel M-8330-B, nickel, Nichrome "V" Magnesium, Fed-QQ-M-44A and Fed-QQ-M-56-A263, titanium C-130AM and C-110AM, copper, brass and Hastalloy. The following nonmetals may be used: Kel-F, Kel-F-5500, Teflon, fluorosilicone rubbers, Fluoroflex "T", glass, Viton "A" and "B", dry asbestos, Garlock 230 and carbon. The following lubricants may be used: Graphitar Nr. 39, Hercules No. 571 Kaobestos, Rockwell Nordstorm Lube No. 921 and Gulf Harmony Oil Nos. 44 and 69. Pentaborane forms shock sensitive mixtures with some solvents. (7)

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Availability: Produced by Callery Chemical Co. No longer in production. A limited quantity is in storage at the present time.

Remarks: For further information see references (15) and (16).

Military Specification, Mil-P-27403, Propellant, Pentaborane

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DIBORANE

Formula: B_2H_6

Physical Properties:

Boiling Point:	-92.5°C	(1)
Freezing Point:	-165.5°C	(1)
Density:	0.437 g/cc @ -92.6°C	(1)
Heat of Formation:	+2.93 Kcal/mole @ -92.5°C	(4)
Vapor Pressure:	---	
Critical Temperature:	16.7°C	(1)
Critical Pressure:	39.5 atm	(1)
Heat of Vaporization	3.413 Kcal/mole @ -92.5°C	(1)
Viscosity:	1.33 millipoise @ -92.5°C	(4)
Specific Heat:	18.5 cal/mole K @ -92.5°C	(1)

Preparation: Diborane may be made by a number of processes. In general, the methods involve the decomposition of a metal borohydride, the reduction of a metal borofluoride, or the reduction of a boron halide. Diborane may be produced by the reaction of an alkali metal borohydride ($LiBH_4$) with boron trichloride in an inert solvent. The diborane is purified by selective liquification at a low temperature. (9)

Toxicity: Diborane is a highly toxic irritant to the pulmonary system. It is not known whether severe or repeated exposure would result in permanent injury. Diborane may impair the sense of smell and therefore odor is not to be relied upon as a means of detection. Cough and tightness in the chest follow immediately upon exposure and serve as a warning. Threshold limit is 0.1 ppm for 8 hr daily exposure. Hazardous exposure occurs only by inhalation. (15)

Sensitivity: Diborane is a very flammable gas with wide explosive limits and high flame and detonation speeds. Although diborane itself is not spontaneously flammable in air at room temperature, it may be ignited by a static spark, heat of reaction, heat of absorption or the spontaneous ignition of one of its thermal decomposition products. (4)

Compatibility: The following materials of construction were found to be suitable for use with gaseous diborane on exposure at ambient temperatures: Teflon, Kel-F, Saran, brass, lead, nickel, K Monel, low carbon steel, stainless steel 18-8, asbestos-graphite-copper valve packing and Vaseline-paraffin-graphite lubricant. (4)

Availability: Limited availability at the present time.

Military Specification, None

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MHF-1

Composition: 45.3% MMH (C_{0.474}H_{5.1195}O_{0.5205}N_{2.2725})
23.3% N₂H₄
34.1% Hydrazinium nitrate (N₂H₅NO₃)

Physical Properties:

Boiling Point:	107.3°C	(21)
Freezing Point:	-54°C	(21)
Density:	1.084 g/cc @ 25°C	(21)
Heat of Formation:*	0.04 Kcal/mole (calc)	(3)
Vapor Pressure:	0.50 psia @ 25°C	(21)
	5.4 psia @ 71°C	(21)
Critical Temperature:	---	
Critical Pressure:	---	
Heat of Vaporization:	---	
Viscosity:	3.6 centistokes @ 25°C	(21)
Specific Heat:	0.62 Btu/lb°F @ 25°C	(21)

MHF-3

Composition: 86% MMH (C_{0.81}H_{5.62}N_{2.0})
14% N₂H₄

Physical Properties:

Boiling Point:	92°C (calc)	(21)
Freezing Point:	-60°C	(21)
Density:	0.90 g/cc @ 15.6°C (calc)	(21)
Heat of Formation:*	12.58 Kcal/mole (calc)	(3)
Vapor Pressure:	0.5 psia @ 15.6°C (calc)	(21)
	9.9 psia @ 79.8°C	(21)
Critical Temperature:	264°C	(21)
Critical Pressure:	93.5 atm	(21)
Heat of Vaporization:	---	
Viscosity:	1.3 centistokes @ 15.6°C	(21)
Specific Heat:	0.71 Btu/lb°F @ 15.6°C	(21)

MHF-5

Composition: 55% MMH (C_{0.541}H_{5.173}O_{0.273}N_{2.091})
26% N₂H₄
19% N₂H₅NO₃

Physical Properties:

Boiling Point:	80°C	(21)
Freezing Point:	-57°C	(21)
Density:	1.011 g/cc @ 25°C	(21)
Heat of Formation:*	5.936 Kcal/mole (calc)	(3)

*Based on composite formula

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Vapor Pressure:	0.77 psia @ 25°C	(21)
	7.7 psia @ 80°C	(21)
Critical Temperature:	---	
Critical Pressure:	---	
Heat of Vaporization:	---	
Viscosity:	1.9 centistokes @ 25°C	(21)
Specific Heat:	0.66 Btu/lb °F @ 25°C	(21)

Preparation: The MHF fuels are prepared by mixing together the individual components.

Toxicity: For toxicity information refer to the section on hydrazine and monomethyl hydrazine. The toxicity limits are estimated to be the same magnitude as the major constituents 0.5 to 1.0 ppm. (21)

Sensitivity: The mixed hydrazine fuels are safe to handle. They have been found to be insensitive to shock by three different tests: JANAF drop weight test, the Frauzl Block test and the JANAF card gap test. MHF-3 was shown to be the safest of the three blends. In addition, MHF-1 has been found not shock sensitive per the ICC explosive test. MHF can form flammable and explosive mixtures in air.

Compatibility: MHF is relatively noncorrosive for most stainless steel and aluminum alloys. The compatibility of MHF-3 was established with aluminum (2014, 2024, 7178), the high-strength steels (AFC-77, AM301, cryogenic stretch-formed) and AM357. The long-term compatibility of aluminum alloys with MHF fuels is excellent. The Hastelloys, Monel, 40E aluminum, magnesium, zinc, lead, copper and its alloys and iron are not recommended for use with MHF. The following non-metals are also compatible with MHF: braided asbestos impregnated with Teflon, Teflon and high-density polyethylene, Garlock 735, Mylar film and unplasticized Kel-F. MHF decomposition in the presence of metals is observed to occur in two phases: a steep initial rate as the surface is passivated and then leveling off to a relatively lower rate characteristic of the material.

Availability: Availability only limited by the availability of the ingredients.

Military Specification, None

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MAP-1

Composition: 40.5% UDMH
50.5% Diethylenetriamine (DETA)
9.0% Acetonitrile (CH_3CN) (22)

Physical Properties:

Boiling Point:	77°C	(22)
Freezing Point:	very viscous at -70°C sets to glass below -100°C	(22)
Density:	0.869 g/cc @ 25°C	(22)
Heat of Formation:*	7.1 Kcal/mole	(22)
Vapor Pressure:	104 mm Hg @ 25°C	(22)
	190 mm Hg @ 40.2°C	(22)
Critical Temperature:	---	
Critical Pressure:	---	
Heat of Vaporization:	---	
Viscosity:	0.58 cp @ 71°C	(22)
Specific Heat	0.67 Btu/lb°F @ 25°C	(22)

Preparation: Prepared by mixing the individual components.

Toxicity: A rough estimate of the toxicity limits can be gained from its components. DETA has a concentration limit of 20 ppm and UDMH has a limit of 0.5 ppm. (22)

Remarks: Additional information on this propellant is not available at this time.

*Based on the composite formula $\text{C}_{2.708}\text{H}_{8.822}\text{N}_{2.196}$

Military Specification, Mil-P-23741, Propellant, Mixed Amine Fuel

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HYBALINE A4

Formula: $C_2NH_{19}AlB_3$

Physical Properties:

Boiling Point:	greater than 220°C	(6)
Freezing Point:	-7.5°C (Melting Pt. +4.5°C)	(6)
Density:	0.759 gm/cc	(6)
Heat of Formation:	-16.5 Kcal/mole	(6)
Vapor Pressure:	2 mm Hg @ 25°C	(6)
Critical Temperature:	---	
Critical Pressure:	---	
Heat of Vaporization:	---	
Viscosity:	9.2 cp @ 20°C	(6)
Specific Heat:	---	

Preparation: $Al(BH_4)_3 + (CH_3)_2NH \longrightarrow (CH_3)_2NH \cdot Al(BH_4)_3$
Reaction carried out in inert solvent such as n-hexane or benzene

Toxicity: Hybaline appears less toxic by inhalation than hydrazine, UDMH, Aerozine 50, pentaborane, diborane, IRFNA and nitrogen tetroxide. Although skin contact with the Hybalines must be avoided, protection requirements are no more stringent than for several of the other high energy fuels. No limits have been established for maximum allowable vapor concentrations. Personnel should not remain in confined areas where significant quantities of Hybaline have been spilled without air supplied respiratory equipment. The decomposition products of Hybaline may contain boron hydrides such as diborane. Skin and eye contact with Hybalines will cause burns and must be avoided. (6)

Sensitivity: Hybaline A is not considered shock sensitive. Negative results have been obtained for No. 6 blasting cap tests and the Olin Mathieson drop weight tester. Hybaline A oxidizes slowly in dry air. However, it readily ignites in moist air or water. Hybaline A should not be exposed directly to the air, but should be handled in an inert atmosphere such as nitrogen or helium. Oxygenated compounds can also ignite Hybaline A. Overheating can result in the release of hydrogen from Hybaline A. All storage tanks should be provided with pressure gauges and over-pressure relief devices to prevent excessive build-up in pressure due to external heating. (6)

Compatibility: Static compatibility testing of Hybaline A-5 has shown the following materials to be compatible: steel, 304 stainless steel, copper, nickel, Monel, tinned iron, galvanized iron, aluminum (2219-T89, 2014-T6), Titanium 110, Teflon, Viton A, Neoprene 7794 and red rubber. Compatibility with A-4 should be the same.

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Availability: Nine hundred pounds of A-4 have been produced by Union Carbide Corp (disregarding A-4 used in preparation of A-5). The production facility is on standby at the present time. Approximately three months would be required to reach full production capacity.
Cost: \$76 a pound.

Remarks: For further information consult reports resulting from Contract AF 04(611)-8164.

Military Specification, None

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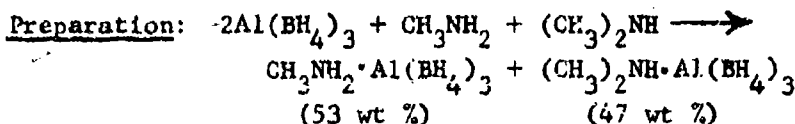
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HYBALINE A5

Formula: $C_{1.47}NH_{17.94}AlB_3$

Physical Properties:

Boiling Point:	263°C	(6)
Freezing Point:	sets to glass below -40°C	(6)
Melting Point:	4°C	(6)
Density:	0.736 gm/cc @ 20°C	(6)
Heat of Formation:	-16.5 Kcal/mole	(6)
Vapor Pressure:	3 mm Hg @ 25°C	(6)
Critical Temperature:	---	
Critical Pressure:	---	
Heat of Vaporization	4990 cal/mole	(6)
Viscosity:	6.78 cp @ 20°C	(6)
Specific Heat:	0.621 cal/gm @ 20°C	(6)



Reaction carried out in inert solvent such as n-hexane or benzene.

Toxicity: Hybaline appears less toxic by inhalation than hydrazine, UDMH, Aerozine 50, pentaborane, diborane, IRFNA and nitrogen tetroxide. Although skin contact with the Hybalines must be avoided, protection requirements are no more stringent than for several of the other high energy fuels. No limits have been established for maximum allowable vapor concentrations. Personnel should not remain in confined areas where significant quantities of Hybaline have been spilled without air supplied respiratory equipment. The decomposition products of Hybaline may contain boron hydrides such as diborane. Skin and eye contact with Hybalines will cause burns and must be avoided. (6)

Sensitivity: Hybaline A is not considered shock sensitive. Negative results have been obtained from No. 6 blasting cap tests and the Olin Mathieson drop weight tester. Hybaline A oxidizes slowly in dry air. However, it readily ignites in moist air or water. Hybaline A should not be exposed directly to the air, but should be handled in an inert atmosphere such as nitrogen or helium. Oxygenated compounds can also ignite Hybaline A. Overheating can result in the release of hydrogen from Hybaline A. All storage tanks should be provided with pressure gauges and over-pressure relief devices to prevent excessive build-up in pressure due to external heating. (6)

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Compatibility: Static compatibility testing of Hybaline A5 has shown the following materials to be compatible: steel, 304 stainless steel, copper, nickel, Monel, tinned iron, galvanized iron, aluminum (2219-T89 and 2014-T6), titanium 110, Teflon, Victon A, Neoprene 7794 and red rubber.

Availability: A total of 11,716 pounds of Hybaline A5 were produced by Union Carbide Corporation under Contract AF 04(611)-8164. Approximately 1/3 of this material remains in storage at the present time. The production facility is now on standby. Approximately three months would be required to reach full production capacity. Cost: \$76 per pound. The projected cost of Hybaline A5 in large production quantities has been established at \$20 per pound for quantities up to 300,000 lbs/yr and \$18 per pound for a production rate of 600,000 lbs/yr.

Remarks: For further information consult reports resulting from Contract AF 04(611)-8164.

Military Specification, None

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HYBALINE B3

Formula: $\text{BeB}_2\text{CH}_{13}\text{N}$

Physical Properties:

Boiling Point:	greater than 270°C	(6)
Freezing Point:	between -80°C & -23°C	(6)
Density:	0.667 gm/cc	(6)
Heat of Formation:	-19.5 Kcal/mole	(6)
Vapor Pressure:	1.5 mm Hg @ 25°C	(6)
Critical Temperature:	---	
Critical Pressure:	---	
Heat of Vaporization:	---	
Viscosity:	3.4 cp @ 20°C	(6)
Specific Heat:	0.625 cal/gm @ 20°C	(6)

Preparation: $\text{Be}(\text{BH}_4)_2 \cdot (\text{C}_2\text{H}_5)_2\text{O} + \text{CH}_3\text{NH}_2 \longrightarrow \text{CH}_3\text{NH}_2 \cdot \text{Be}(\text{BH}_4)_2$
Reaction carried out in petroleum ether or diethyl ether.

Toxicity: The main consideration in the use of Hybaline B3 is the beryllium toxicity. The manifestations of beryllium poisoning have been divided into three classes: acute berylliosis, chronic berylliosis and dermatitis. The more serious effects are due entirely to inhalation of beryllium or its compounds. The onset of symptoms accompanying chronic berylliosis may be delayed as much as 10 years or longer after the last exposure. (8) In addition to beryllium toxicity, skin and eye contact with B3 will cause burns. (6)

Sensitivity: The same considerations apply to B3 as apply to Hybaline A (See Hybaline A5). (6)

Compatibility: The compatibility should resemble the Hybaline A series (See Hybaline A5). (6)

Availability: A total of 199 pounds of B3 were produced by Union Carbide Corp under Contract AF 04(611)-8164. The production facility is on standby at the present time. Cost: \$300 a pound. A limited quantity is available at the present time. (8)

Remarks: For further information consult reports resulting from Contract AF 04(611)-8164.

Military Specification, None

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GELS AND EMULSIONS

The performance of many propellant systems can be improved by the addition of the light metal or their hydrides. Gel and emulsion techniques are used to provide a uniform distribution of the metal or hydride in the fuel. (29)

Gels:

A gel is obtained by either chemically or mechanically immobilizing the liquid and trapping the metal or hydride dispersed throughout the liquid. The gel should have a sufficiently high yield stress to support the suspended solid and prevent it from settling out as a result of normal handling and storage. Ideally the gel acts like a solid during static conditions yet behaves like a liquid under flow conditions (low apparent viscosity). (28) (29)

Gelling agents may be divided into roughly two categories: particulate and swellable agents. Particulate gelling agents depend on the ability of the particles to bond to one another by attractive forces in order to form the necessary suspension network. Swellable agents are materials (e.g. organic polymers and natural gums) which appear to depend on the physicochemical interaction between the gelling agent and the carrier fluid.

Physical Properties of Alumazine - 43G:

Boiling Point:	NA, est. approx. 114°C	(29)
Freezing Point:	0°C	(29)
Density:	1.366-1.380 g/cc @ 77°F	(29)
Vapor Pressure:	0.27 psi @ 25°C	(29)
	1.8 psi @ 60°C	(29)
Yield Stress:	1400 to 2200 dyne/sq cm @ 25°C	(29)
Apparent Viscosity @ 25°C:		
(Ferranti-Shirley Viscosimeter)	29 to 41 cp (17,300 sec ⁻¹)	(29)
	400 to 600 cp (300 sec ⁻¹)	(29)
	700 to 1300 cp (100 sec ⁻¹)	(29)
Apparent Viscosity:		
(Brookfield, Spindle No. 4, 6 rpm)	35,000 to 60,000 cp @ 25°C	(29)

Emulsions:

A heterogeneous emulsion consists of a continuous liquid external phase in which a discontinuous, immiscible liquid internal phase is dispersed. The internal phase exists as discrete globules that are held in suspension by the action of surface tension in the external phase. The metal or hydride is contained in the internal phase and can settle to the bottom of the droplets but is prevented from settling further due to the interface between the internal and external phases. As long as the emulsion does not break, the particles cannot settle out. The yield stress of an emulsion is the point at which the internal phase globules can "flow" and does not necessarily represent the point at which settling will occur. (29)

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Problem Areas:

1. Selection of gelling or emulsifying agent
2. Compatibility of components
3. Mechanical and chemical stability
4. Batch-to-batch uniformity

Remarks:

Additional information can be found in (28), (29) and "Bulletin of the 7th Liquid Propulsion Symposium," Volume 1, 19-21 October 1965, CPIA. Publication No. 72, August 1965. (Confidential)

Military Specification, Mil-P-27412, Propellant, Aluminum Hydrazine

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III. LIQUID PROPELLANT PROPERTIES

(Oxidizers)

3.0

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OXYGEN

Formula: O_2

Physical Properties:

Boiling Point:	-183.0°C	(1)
Freezing Point:	-218.8°C	(1)
Density	1.14 g/cc @ -183°C	(1)
Heat of Formation:	-3.08 Kcal/mole @ 90.2°K	(3)
Vapor Pressure:	---	
Critical Temperature:	-118.9°C	(1)
Critical Pressure:	49.7 atm	(1)
Heat of Vaporization:	1.63 Kcal/mole @ 1 atm	(1)
Viscosity:	0.190 cp @ -183.0°C	(1)
Specific Heat:	0.406 cal/gm°C @ -183.0°C	(1)

Preparation: Liquid oxygen is obtained from liquid air by fractional distillation. (9)

Toxicity: Non-toxic. If liquid oxygen spills on skin, injury resembling a burn will result. Oxygen gas will not cause toxic effects in propellant operations, except that inhalation of very cold oxygen gas may cause some irritation of the upper respiratory tract. (7)

Sensitivity: Liquid oxygen is chemically stable. It is not shock sensitive and will not decompose. (7)

Compatibility: Materials to be used in liquid oxygen equipment must possess satisfactory physical properties at extremely low operating temperatures. Acceptable materials are: stainless steel series 18-8, copper, bronze, brass, Monel, aluminum, everdur, Teflon, Kel-F, Asbestos and special silicone rubbers. Petroleum-base lubricants must not be used. Special lubricants such as the fluorolubes or the perfluorocarbons can be used. (7)

Availability: Liquid oxygen is readily available at \$38.25 per bulk-ton.

Military Specification, Mil-P-25508, Propellant, Oxygen

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FLUORINE

Formula: F_2

Physical Properties:

Boiling Point:	-188°C	(1)
Freezing Point:	-219.6°C	(1)
Density:	1.505 g/cc @ -188°C	(1)
Heat of Formation:	-3.467 Kcal/mole @ 85.2°K	(3)
Vapor Pressure:	---	
Critical Temperature:	-129.2°C	(1)
Critical Pressure:	55 atm	(1)
Heat of Vaporization:	1.560 Kcal/mole @ -188°C	(1)
Viscosity:	0.24 cp @ -188°C	(1)
Specific Heat:	0.367 cal/gm°C @ -188°C	(1)

Preparation: Fluorine is produced from a molten mixture of HF and KF by an electrolytic procedure. (9)

Toxicity: If liquid fluorine comes in contact with the body, it will cause skin injuries resembling burns that are likely to be severe, deep and slow in healing. Exposure to fluorine gas is a more likely accident. The gas is highly irritating to the eyes and to the upper and lower respiratory tract. Repeated exposure to the gas may cause chronic pulmonary damage. The threshold limit value of fluorine is 0.1 ppm (0.2 mg/cu m). (7)

Sensitivity: Unconfined fluorine is stable to shock, heat and electrical spark. Containers of fluorine, however, must not be subjected to shock or heat, as a violent reaction with the container is possible. (7)

Compatibility: Liquid compatible with: Monel, aluminum, stainless steel (types 304L, 321 and 347), copper and brass. Gaseous fluorine compatible with: nickel, Monel, steel, stainless steel, bronze, copper, aluminum and magnesium. Teflon, Kel-F and Halon are acceptable non-metals for use at moderate pressures and low flow rates. Spray coated or calcined aluminum oxide is resistant to gaseous and liquid fluorine under flow conditions and at low as well as high temperatures (several hundred degrees C). There are no plastics acceptable for use with liquid fluorine under flow conditions. There are no reliable lubricants for fluorine service. (7)

Availability: Cost: \$3.55 a pound, Projected cost: \$1.00 a pound. (9)

Military Specification, Mil-P-27405, (Unapproved)

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IRFNA

Formula: $H_{0.879}N_{0.972}O_{2.799}$

Physical Properties:

Boiling Point:	65.6°C	(1)
Freezing Point:	-50°C	(1)
Density:	1.564 g/cc @ 15°C	(1)
Heat of Formation:	-41 Kcal/mole	(1)
Vapor Pressure:	---	(1)
Critical Temperature:	---	
Critical Pressure:	---	
Heat of Vaporization:	---	
Viscosity:	0.863 cp @ 21.2°C	(1)
Specific Heat:	0.417 cal/gm @ 20°C	(1)

Preparation: Nitric acid is made by the catalytic oxidation of ammonia with air or oxygen to yield nitric oxide (NO). The latter is oxidized to N_2O_4 which when treated with water, yields nitric acid and may be concentrated by distillation with sulfuric acid. Red fuming nitric acids may be produced by passing gaseous N_2O_4 into nitric acid. (9)
The % composition of IRFNA is as follows:

	NO_2	H_2O	HNO_3	Solids	HF
Type IIIA	14	1.5-2.5	81.6-84.8	0.10 max	0.7
Type IIIB	14	1.5-2.5	81.6-84.8	0.04 max	0.7

Toxicity: Because the liquid is highly corrosive, skin and eyes can be severely burned by more than momentary contact. Another serious hazard in the handling of fuming nitric acids is the inhalation of toxic vapors, especially nitrogen dioxide. The threshold limit value of nitrogen dioxide is 5 ppm. The chief danger from acute poisoning is the development of pulmonary edema, when the lung spaces fill with fluid. The symptoms may be delayed for several hours. The color of the fumes is not a reliable index of the degree of toxic hazard. The initial symptoms of poisoning - irritation of the eyes and throat, cough, tightness of the chest and nausea - are slight and may not be noticed. Then some hours later, severe symptoms begin; their onset may be sudden and precipitated by exertion. Coughing, a feeling of constriction in the chest and difficult breathing develop. (7)

Sensitivity: Nitric acid is stable to all types of mechanical shock and impact. (7)

Compatibility: The following metals may be used with nitric acid: aluminum (types 1060, EC, 1100, 3003, 3004, 6061, 5052 and 5154) and stainless steel (347, 19-9DL, 19-9DX, 304 ELC, 321, 303 and 316).

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All other ferrous and nonferrous metals and their alloys are prohibited. The following nonmetals may be used: Kel-F, Teflon, polyethylene and Resin-X. The following lubricants may be used: Nordcoseil-147-5, Fluorolube and Perfluorocarbons. (7)

Availability: YRFNA is readily available at from \$.06 to \$.10 per pound depending upon type and quantity.

Remarks: For additional information consult reference (7) on the latest military specification.

Military Specification, Mil-P-7254, Propellant, Nitric Acid

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HYDROGEN PEROXIDE

Formula: H_2O_2 (100%)

Physical Properties:

Boiling Point:	150.2°C	(1)
Freezing Point:	-0.461°C	(1)
Density:	1.4425 g/cc @ 25°C	(1)
Heat of Formation:	-44.75 Kcal/mole @ 25°C	(1)
Vapor Pressure:	.0263 psia @ 20°C	(1)
	0.5762 psia @ 70°C	(1)
Critical Temperature:	457°C	(1)
Critical Pressure:	214 atm	(1)
Heat of Vaporization:	12.334 Kcal/mole @ 25°C	(1)
Viscosity:	1.249 cp @ 20°C	(1)
Specific Heat:	0.632 cal/gm @ 25°C	(1)

Preparation: Hydrogen peroxide is manufactured commercially by several processes. Inorganic processes employ the electrolysis of an aqueous solution of sulfuric acid or acidic ammonium bisulfate, followed by hydrolysis of the peroxydisulfate which is formed. Organic processes include (1) the auto-oxidation of hydroquinone or one of its homologues in a suitable solvent system and (2) the partial gas-phase oxidation of hydrocarbons. Dilute aqueous hydrogen peroxide is concentrated to about 90% by conventional distillation. Higher strength solutions are prepared by fractional crystallization of 90% feed stock. (9)

Toxicity: Contact with the liquid, mist or vapor produces irritant effects. When the liquid touches the skin, there is a burning sensation and the affected areas are bleached. Prolonged contact can cause burns. Inhaling the vapor irritates the respiratory tract and may result in burning of the nose and throat, running of the nose and coughing. The vapors can also irritate the eyes. Exposure to high concentrations of a mist or aerosol of hydrogen peroxide, if not washed away promptly, can result in delayed but severe damage to the eyes. The threshold limit value of 90% hydrogen peroxide is 1 ppm. (7)

Sensitivity: Pure hydrogen peroxide in properly passivated containers decomposes at a very slow rate. If stored in containers of unsuitable material or if contaminated, hydrogen peroxide can decompose very rapidly, releasing large amounts of heat and gas. (7)

Compatibility: Proper selection and passivation of materials for handling hydrogen peroxide are essential. Contact of the peroxide with incompatible metals or plastics or with nonpassive surfaces anywhere in the storage system can lead to dangerous conditions. Certain aluminums, the 300-series stainless steels and other materials have only a slight effect on the stability of hydrogen peroxide and may be used for materials of construction. Tanks for long-term storage (one week or

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more) are constructed of 1060, 1260, 5254 or 5652 aluminum. Teflon and Kel-F are suitable for flexible long-term storage containers; for periods of less than one week, some polyvinyl chloride plastics and silicone rubbers may be used. Wrought A151 300-series stainless steels are suitable for short-term storage. (7)

Availability: Available at \$.31 to \$.43 per pound.

Military Specification, Mil-P-16005, Propellant, Hydrogen Peroxide

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CHLORINE TRIFLUORIDE

Formula: ClF_3

Physical Properties:

Boiling Point:	11.75°C	(1)
Freezing Point:	-76.3°C	(1)
Density:	1.8806 g/cc @ 1.70°C	(1)
Heat of Formation:	-42.94 Kcal/mole	(3)
Vapor Pressure:	495 mm Hg @ 0°C	(1)
Critical Temperature:	174°C	(1)
Critical Pressure:	57 atm	(1)
Heat of Vaporization:	6,580 cal/mole @ 11.75°C	(1)
Viscosity:	4.78 cp @ 11.75°C	(1)
Specific Heat:	0.303 cal/gm @ 20°C	(3)

Preparation: ClF_3 is prepared by direct combination of the elements. (9)

Toxicity: The liquid is highly corrosive; contact with skin or eyes could result in deep, painful burns. Exposure to the vapor causes irritation of the eyes and the upper and lower respiratory tracts. If concentrations are high enough, pulmonary edema may result and death may follow if quick action is not taken. Threshold limit is 0.1 ppm. (7)

Sensitivity: CTF is stable to shock, heat and electrical spark. (7)

Compatibility: Such metals as copper, silver-solder, brass, steel, magnesium, aluminum, Monel or nickel are satisfactory for use with CTF owing to the formation of a passivating fluoride film. Monel, 18-8 stainless steel and nickel are preferred. Approved nonmetals, which may ignite when heated are: Neoprene (for protective clothing only), Kel-F (not recommended for flow conditions), Teflon (not recommended for flow conditions) and pyrex glass. The use of the standard petroleum-base lubricant is prohibited. Fluorinated hydrocarbons may react violently with CTF. No completely satisfactory lubricant is known. (7)

Availability: Present cost: \$3.20 per pound. Large scale production could reduce cost to \$.50/lb. (9)

Military Specification, Mil-P-27411, Propellant, Chlorine Trifluoride
(Unapproved)

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NITROGEN TETROXIDE

Formula: $N_2O_4 \rightleftharpoons 2NO_2$

Physical Properties:

Boiling Point:	21.3°C	(1)
Freezing Point:	-11.35°C	(1)
Density:	1.45 g/cc @ 20°C	(1)
Heat of Formation:	-4.5 Kcal/mole	(26)
Vapor Pressure:	5.0 psia @ 0°C	(1)
	14.0 psia @ 20°C	(1)
Critical Temperature:	158°C	(1)
Critical Pressure:	100 atm	(1)
Heat of Vaporization:	9.11 Kcal/mole @ 21.15°C	(1)
Viscosity:	4132 micropoise @ 21.15°C	(1)
Specific Heat:	0.368 cal/gm @ 20°C	(1)

Preparation: Nitrogen dioxide is made by the catalytic oxidation of ammonia; steam is used as a diluent to reduce the combustion temperature. Most of the water is condensed out, and the gases are further cooled; the nitric oxide is oxidized to nitrogen dioxide, and the remainder of the water is removed as nitric acid. The gas is essentially pure nitrogen tetroxide, which is then condensed. (9)

Toxicity: The liquid is corrosive and severe burns of the skin and eyes can result if not immediately removed. The inhalation of toxic vapors is normally the most serious hazard in handling nitrogen tetroxide. The threshold limit of the fumes is 5 ppm expressed as nitrogen dioxide, or 2.5 ppm expressed as nitrogen tetroxide. The main danger from acute poisoning is the development of pulmonary edema which normally develops a considerable time after exposure to the fumes. The color of the fumes is not a reliable index of degree of toxic hazard. The initial symptoms of poisoning - irritation of the eyes and throat, cough, tightness of the chest and nausea - are slight and may not be noticed. Severe symptoms begin hours later. Repeated exposure to these fumes at low concentration levels may cause ulceration of the nose and mouth, wearing down and decay of teeth and chronic irritation of the entire respiratory tract. (7)

Sensitivity: Nitrogen tetroxide is very stable at room temperature. At 302°F it begins to dissociate into nitric oxide and free oxygen. Upon cooling it reforms into nitrogen tetroxide. (7)

Compatibility: Nitrogen tetroxide is not corrosive to most common metals at ordinary temperatures and pressures. The selection of metals should however be governed by the oxidizer's moisture content. When the NO_2 moisture content is 0.1% or less the following metals can be used: carbon steels, aluminum, stainless steels, nickel and Inconel. Under wet conditions stainless steel (300 series) should be used. The

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following nonmetals may be used: ceramic (acid resistant), pyrex glass, Teflon, Kal-F, asbestos (cotton-free) and polyethylene (limited use). Hydrocarbon lubricants must be avoided. Fluorolube series, Teflon tape, Nordcoseal-147 and DC2345 lubricant may be used. (7)

Availability: Readily available at \$0.09/lb.

Military Specification, Mil-P-26539, Propellant, Nitrogen Tetroxide

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PERCHLORYL FLUORIDE

Formula: ClO_3F

Physical Properties:

Boiling Point:	-46.8°C	(1)
Freezing Point:	-146°C	(1)
Density:	$1.692 \text{ g/cc @ } -46.8^\circ\text{C}$	(1)
Heat of Formation:	$-5.12 \text{ Kcal/mole (g) @ } 25^\circ\text{C}$	(1) (2)
	$-10 \text{ Kcal/mole (l)}$	(3)
Vapor Pressure:	---	
Critical Temperature:	95.2°C	(1)
Critical Pressure:	53.0 atm	(1)
Heat of Vaporization:	$4.6 \text{ Kcal/mole @ } -46.8^\circ\text{C}$	(1)
	$3.5 \text{ Kcal/mole @ } 25^\circ\text{C}$	(1)
Viscosity:	$0.219 \text{ cp @ } 0.0^\circ\text{C}$	(1)
Specific Heat:	$0.226 \text{ cal/mole}^\circ\text{C @ } -46.46^\circ\text{C}$	(1)

Preparation: Perchloryl fluoride may be prepared by the electrolysis of a mixture of sodium perchlorate (NaClO_4) and hydrofluoric acid (HF). Fluorination of KClO_3 will also yield the oxidizer. (9)

Toxicity: Should liquid PF splash onto the skin, irritation or moderate to severe burns may result, depending on the amount spilled and the length of time it remains on the skin. Exposure to moderate to high concentrations of the vapor causes respiratory irritation and methemoglobinemia, which, if severe, is accompanied by cyanosis (blue tinge to certain mucous membranes). Repeated exposure to lower concentrations may cause anemia and the deposit of fluoride in bones and teeth. The threshold limit for perchloryl fluoride is 3 ppm. (7)

Sensitivity: Perchloryl fluoride is thermally stable up to 850°F . At 500 to 575°F , it hydrolyzes slowly with water to form HClO_4 and HF at room temperature. (7)

Compatibility: Although at ordinary temperatures perchloryl fluoride is not corrosive to most common metals, moisture content of the PF should be the governing factor in selecting a metal for this service. The following metals are approved for use with Anhydrous PF: carbon steel, aluminum, stainless steel, copper, brass and bronze. For PF and water vapor the following can be used: stainless steel (types 304, 310 and 314), Hastelloy, tantalum, Durimet "T" and Durimet-20. Owing to the lack of operational and long term data, the only non-metal materials that can be recommended for severe service with PF in a situation where pressure or flow phenomena may irritate combustion or detonation are Kel-F and Teflon. Perchloryl fluoride

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should never be brought into contact with conventional or petroleum greases, oils, pipe compounds, etc. The only lubricants found to be suitable are the fluorocarbons. (7)

Availability: Perchloryl fluoride is available in small quantities from several chemical companies. Projected cost: \$1.50 per pound. (9)

Military Specification, None

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OXYGEN DIFLUORIDE

Formula: OF_2

Physical Properties:

Boiling Point:	-145.3°C	(5)
Freezing Point:	-223.8°C	(5)
Density:	1.546 g/cc @ -148.52°C	(5)
Heat of Formation:	-7.4 Kcal/mole	(26)
Vapor Pressure:	---	
Critical Temperature:	-59.7°C	(5)
Critical Pressure:	49.5 atm	(5)
Heat of Vaporization:	2.66 Kcal/mole @ -145.3°C	(5)
Viscosity:	0.323 cp @ -155.8°C	(5)
Specific Heat:	10.35 cal/mole°C @ 298°C	(5)

Preparation: Oxygen difluoride is prepared by reacting elemental fluorine with dilute aqueous solution of sodium or potassium hydroxide, according to the following reaction:



Only 50 percent of the original fluoride, at best, is recovered as the oxygen difluoride. (9)

Toxicity: Precise and accurate data defining the toxicity of OF_2 is not available. Oxygen difluoride is a lethal gas, comparable to phosgene, and has a peculiar smell similar to that of elemental fluorine. It penetrates deep into the lungs by passing the bronchus and dissolves in the delicate tissues. The full effect develops sometime after inhalation producing a delayed edema. The symptoms are evidenced by a difficulty in breathing, irresistible coughing, emetic irritation, as well as a general tight feeling in the chest. A practical operating guide is to limit personnel exposures to the levels practiced in handling pentaborane 0.005 ppm. (5)

Sensitivity: Oxygen difluoride is insensitive to shock at -196°C using the Trauzl sensitivity test. The decomposition of OF_2 is appreciable only above 250°C. (5)

Compatibility: Cleanliness and smooth surfaces are important for successful operation with OF_2 .

Liquid OF_2 compatibility:

Aluminum alloys for short term applications

Nickel alloys are perhaps most satisfactory (e.g. Monel)

Stainless steels are most widely used for construction, however, long term servcability has not been established

Copper and copper alloys, titanium alloys and magnesium alloys seem to have limited adaptability to long-term liquid operations

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Plastics and elastomeric materials are limited because of cryogenic temperatures

Teflon and Kel-F are compatible for short periods of time. Gaseous OF_2 service requirements do not appear to be more severe than the liquid requirement. At elevated temperatures, however, the decomposition into fluorine and oxygen must be taken into consideration. (5)

Availability: Currently the only source of commercial quantities of OF_2 is the Allied Chemical Corporation. The present cost is \$35 per pound available in nine pound cylinders. The lowest price forecast based on synthesis from fluorine is \$30/lb. Thiokol-RMD has conducted a cost analysis on an electrolytic OF_2 process based on HF resulting in cost estimates as low as \$.50/lb² for large scale production. (5)

Remarks: For additional information consult reports resulting from Contract AF 04(611)-8400. Reference (5) lists 49 additional references.

Military Specification, None

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TETRAFLUOROHYDRAZINE

Formula: N_2F_4

Physical Properties:

Boiling Point:	-74°C	(18)
Freezing Point:	-163°C	(15)
Density:	1.65 g/cc @ -73.0°C	(18)
Heat of Formation:	-2.0±2.5 Kcal/mole (g)	(18)
	-5 Kcal/mole (l)	(3)
Vapor Pressure:	---	
Critical Temperature:	36°C	(18)
Critical Pressure:	41.5 atm	(18)
Heat of Vaporization:	3710 cal/mole	(18)
Viscosity:	---	
Specific Heat:	19.06 cal/mole°C @ 25°C	

Preparation:

1. Pyrolysis of nitrogen trifluoride over various metals such as stainless steels, copper and arsenic.
2. Homogeneous reaction of nitrogen trifluoride with mercury in an electric discharge.
3. Vapor phase reaction of fluorine and ammonia in a packed copper reactor.
4. Thermal pyrolysis of nitrogen trifluoride over carbon. (18)

Toxicity: Tetrafluorohydrazine must be considered highly toxic and hazardous to humans. Skin contact and inhalation must be avoided. Studies on rats demonstrated that it causes respiratory irritation and methemoglobinemia. Pulmonary edema and kidney damage were also detected. Repeated exposures are insidious, producing systemic damage even at low concentrations. (18)

Sensitivity: Tetrafluorohydrazine has been involved in countless explosions. Extreme caution should be exercised when dealing with this compound especially when impurities are present. (18)

Compatibility: At moderate temperatures the following materials have been used successfully with N_2F_4 : pyrex glass, nickel, copper, carbon steel, polyethylene, stainless steel, brass, Monel, Teflon and Kel-F. Nickel and Monel are recommended for high temperature work. Pyrex glass and stainless steel have been used successfully at liquid nitrogen temperatures. (18)

Availability: Available only by contract. Air Products has the only plant now in existence. No cost data available.

Remarks: Additional references cited in ref (18).

Military Specification, None

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COMPOUND A

Formula: ClF_5

Physical Properties:

Boiling Point:	-13.1°C	(19)
Freezing Point:	-103°C	(19)
Density:	$1.793 \text{ g/cc @ } 20^\circ\text{C}$	(19)
Heat of Formation:	$-60 \pm 5 \text{ Kcal/mole}$	(19)
Vapor Pressure:	---	
Critical Temperature:	143°C	(19)
Critical Pressure:	52.3 atm	(19)
Heat of Vaporization:	$5.313 \text{ Kcal/mole @ } -13.1^\circ\text{C}$	(19)
Viscosity:	$3.245 \text{ cp @ } 20^\circ\text{C}$	(19)
Specific Heat:	$0.3355 \text{ cal/gm}^\circ\text{K @ } 20^\circ\text{C}$	(19)

Preparation: Chlorine pentafluoride is prepared by a continuous process, homogeneous gas-phase reaction of elemental fluorine and chlorine. The current production facility has a maximum operating range of 2000 psig and 600°F . The reaction normally is carried out at 200°F and between 1000 and 1500 psig. (19)

Toxicity: No limits have been established at the present time. It should be treated similar to chlorine trifluoride which has a threshold limit of 0.1 ppm. (19)

Sensitivity: All tests have shown ClF_5 to be insensitive to initiation and will not propagate a detonation. (19)

Compatibility: Compound A has been tested with Monel, nickel, Inconel-X, Hastelloy C, aluminum, stainless steel, copper and Teflon. Essentially all materials tested were compatible in uncontaminated ClF_5 . When ClF_5 or the materials were contaminated with moisture only Hastelloy C or nickel 200 provided complete resistance to attack. No change in composition of the ClF_5 or in any of the tests was detectable. (19)

Availability: Currently ClF_5 is not commercially available because of its classification. Several companies will supply small quantities at an estimated cost of \$50 per pound to government contractors. Projected cost in large quantities is between \$0.50 and \$1.00 per pound.

Remarks: Consult reports generated under Contract AF 04(611)-7023 and Contract AF 04(611)-9563 for additional information.

Military Specification, None

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OZONE

Formula: O_3

Physical Properties:

Boiling Point:	-111.9°C	(1)
Freezing Point:	-192.7°C	(1)
Density:	1.46 g/cc @ -112°C	(1)
	1.571 g/cc @ -183°C	(1)
Heat of Formation:	+34.4 Kcal/mole @ 25°C	(3)
Vapor Pressure:	---	
Critical Temperature:	-12.1°C	(1)
Critical Pressure:	54.8 atm	(1)
Heat of Vaporization:	3,410 cal/mole @ -111.9°C	(1)
Viscosity:	1.56 cp @ -183.0°C	(1)
Specific Heat:	17 cal/mole @ -111.9°C	(1)

Preparation: Purified oxygen is fed into an electric discharge or between highly charged plates. The reaction $3O_2 \rightarrow 2O_3$ takes place leaving a concentration of from 1 to 6 weight percent ozone. This mixture is introduced into a refrigerated vessel where the ozone condenses out at -111.9°C and 1 atm partial pressure. (1)

Toxicity: The reaction on the human skin is similar to that of liquid oxygen and the coldness will cause severe "burns". Liquid ozone at temperatures above the boiling point of liquid oxygen will give off high concentrations of gaseous ozone and there is the danger of building up to a toxic concentration. Concentrations of 1 ppm may be readily detected by the human nose. The maximum allowable concentration for an eight hour period is 0.1 ppm. Concentrations up to 20 ppm may be considered nontoxic if the exposure time is short. (1)

Sensitivity: One estimate of the stability of liquid ozone is that at -183°C its sensitivity is comparable to that of nitroglycerin at room temperature. Gaseous ozone at room temperature appears to be less stable than liquid ozone. Very pure ozone (impurities of less than 2ppm) has shown measurable, spontaneous decomposition at room temperature in clean glass containers. (1)

Compatibility: The following materials have been shown to be compatible with 100% ozone (gaseous and liquid): aluminum (25, 35, 245, 525 and 615), stainless steel (302, 304, 316, 410 and 416), Kel-F, Teflon, Fluorocarbon greases, Kovar, pyrex and silver solders. Some materials are compatible with liquid ozone but not with the gas. (1)

Availability: Because of stability problems associated with concentrated ozone, it is costly, hazardous to concentrate and difficult to transport and store. Concentrated ozone in either gaseous or liquid form is usually produced and used as needed. (1) The projected cost of ozone if required in large quantities is \$0.09.

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Remarks: Additional information is contained in Thorp, C. E.,
Bibliography of Ozone Technology, Vol 2, Armour Research Founda-
tion, Chicago, Illinois (1955).

Military Specification, None

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MOXY 2

Composition: A mixture of tris (difluoramino) fluoromethane (Compound R), tetrafluorohydrazine (N_2F_4) and perchloryl fluoride (ClO_3F). (20)

MOXY-2a

$R/N_2F_4/ClO_3F :: 30.3/61.8/7.9$ mole %

Physical Properties:

Boiling Point:	about $-80^{\circ}C$	(20)
Freezing Point:	very viscous at $-135^{\circ}C$	(20)
Density:	1.446 g/cc @ $0^{\circ}C$	(20)
	1.335 g/cc @ $25^{\circ}C$	(20)
Heat of Formation:	-18.7 Kcal/mole	(20)
Critical Temperature:	$85^{\circ}C$	(20)
Viscosity:	0.268 cp @ $0^{\circ}C$	(20)

Preparation: $FC(NF_2)_3$ is prepared by the direct fluorination of ammeline. The mixture is prepared by condensing the components together in a closed vessel. (20)

Toxicity: Preliminary tests indicate that Moxxy-2 toxicity should be based on the component N_2F_4 . No threshold value has been set. (20)

Sensitivity: Moxxy 2a is less sensitive than n-propyl nitrate as tested in an adiabatic U-tube tester, however, it is sensitive to change in flow conditions, especially at sharp turns in lines while the mixture is flowing.

Compatibility: Platinum was the only metal showing no attack whatsoever after exposure to the oxidizer at $43^{\circ}C$ for a period of several weeks. Stainless steels 347 and 316, Monel and pure aluminum developed light colored films. Stainless steel 304, iron, copper, nickel, Hastalloy B, aluminum E.C. alloy and tantalum exhibited moderate surface attack by formation of fairly heavy surface coatings, all of which could be scraped off. Teflon is the most satisfactory of the nonmetals tested, while Butyl and Buna-N are marginal. (20)

Availability: There is no known source producing Moxxy 2a at this time.

Remarks: For additional information consult reports generated under Contract AF 04(611)-8182. Initial small engine test firings with Moxxy 2a and N_2H_4 showed that this oxidizer was too shock sensitive to safely handle.

Military Specification, None

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TETRAKIS (DIFLUORAMINO) METHANE

(Compound T) (Delta)

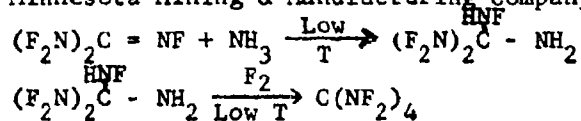
Formula: $C(NF_2)_4$

Physical Properties:

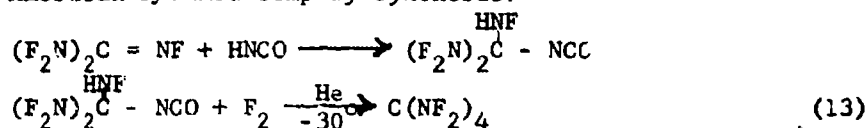
Boiling Point:	40.2°C	(13)
Freezing Point:	-20°C	(13)
Density:	1.65 gm/cc @ 25°C	(13)
Heat of Formation:	+13.5 Kcal/mole	(17)
Vapor Pressure:	---	
Critical Temperature:	---	
Critical Pressure:	---	
Heat of Vaporization:	6.4 Kcal/mole	(13)
Viscosity:	---	
Specific Heat:	---	

Preparation:

a. Minnesota Mining & Manufacturing Company synthesis:



b. American Cyanamid Company synthesis:



Toxicity: Compound "T" should be considered to be as toxic as chlorine trifluoride.

Sensitivity: This compound is highly shock sensitive.

Compatibility: Compatibility should resemble that of chlorine trifluoride.

Availability: Not commercially available. It has only been made in gram quantities in the laboratory.

Military Specification, None

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IV. LIQUID PROPELLANT PROPERTIES
(Monopropellants)

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MONEX D

Formula: A thixotropic mixture of beryllium (16.6%), hydrazine nitrate (28.7%), hydrazine (37.5%) and water (17.0%). This composition along with 0.3% gelling agent has been designated MONEX DW 17 G.3

Physical Properties:

Freezing Point:	-57.3°C	(30)
Density:	1.229 g/cc @ 25°C	(30)
Vapor Pressure:	9 mm Hg @ 25°C	(30)
Specific Impulse:	306 sec	(30)

Preparation: The composition is formed by mixing the components together in a moisture free atmosphere.

Toxicity: Monex D is very toxic due to the presence of beryllium. Beryllium handling methods and precautions must be used when working with this propellant.

Sensitivity: Monex DW 17 G.3 has been found to be insensitive to shock using the standard impact sensitivity test, the card-gap test and thermal stability test for monopropellants. During preparation, however, the sensitive nature of hydrazine nitrate must be considered.

Compatibility: The compatibility of Monex D is determined by its components. Materials usable with hydrazine should be compatible with Monex.

Availability: Monex is still in the development stage. Only laboratory samples have been prepared to date.

Remarks: For additional information consult reports resulting from Contract AF 04(611)-9713.

Military Specification, None

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V. LIQUID PROPELLANT
THEORETICAL PERFORMANCE SUMMARY

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SUMMARY OF MAXIMUM THEORETICAL SPECIFIC IMPULSE
(1000/14.7 psia)
(Shifting Equilibrium)

	N_2H_4	MMH	UDMH	50/50	RP-1	H_2	NH_3	P_5H_9	B_2H_6	MHF-1	MHF-3	MHF-5	MAF-1	Hyb A4	Hyb A5	Hyb B3
Oxygen	313	306	310	312	300	391		327	349	301	312	307	303	324	326	330
Fluorine	363	346	344	349	318	410	357	360	363	348	347	352	303			
IRFNA	278	278	272	272				298							297	305
Hydrogen Peroxide	286	285	283	283		322	263	316	334	278	281	284	281	305	309	313
Chlorine Trifluoride	293	283	280	283		316		290			282	285	270	286		
Nitrogen Tetroxide	291	288	286	289	277	342	262	306	321	282	286	287	281	302	306	316
Perchloryl Fluoride	295	291	290			344		306								
Oxygen Difluoride	339	343		342	341	401		354	365					349		
Tetrafluoro-hydrazine	334	327			297			334								
Chlorine Pentafluoride	311	298	292	300	269					295	299	303	287	302		
Ozone	334				329	427										
Moxy 2	315	305	301	307	287	343				310	306	303	294			
Compound "T" - N_2C_2	326															
$O_2/F_2/O_3$ 30/10/60	328				323	415										
N_2H_4								324								

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SUMMARY OF MAXIMUM THEORETICAL SPECIFIC IMPULSE (Cont.)

(1000/14.7 psia)

(Shifting Equilibrium)

	$N_2H_4-AI-33$	$N_2H_4-AI-43$	N_2H_4-B-25	$N_2H_4-Be-35$	$N_2H_4-Be-45$	$MMH-Be-45$	$N_2H_4-AIH_3-25$	$N_2H_4-AIH_3-35$	$N_2H_4-AIH_3-45$	$MMH-BeH_2-45$
Oxygen	314	310								353
Hydrogen Peroxide	301	304	333	332	323	323	299	307	316	349
Chlorine Trifluoride	290	287	304	303	305		296	295	295	307
Nitrogen Tetroxide	304	299	325	315	304		305	312	316	336
Chlorine Pentafluoride	306	303	320	317	317		313	313	312	323
Moxy /	313									

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SUMMARY OF MAXIMUM THEORETICAL DENSITY IMPULSE

(1000/14.7 psia)

(Shifting Equilibrium)

	N_2H_4	MMH	UDMH	50/50	RP-1	H_2	NH_3	B_5H_9	MHF-1	MHF-3	MHF-5	MAF-1	Hyb A4	Hyb A5	Hyb B3
Oxygen	335		304	319		159		302	336	319	330	313	313	310	301
Fluorine	478		413	444		297		454	461	440	463	313			
IRFNA														355	349
Hydrogen Peroxide	363		354	354		209	302	367	361	359	365	360	359		365
Chlorine	436	282	385	414		289		446		411	431	387	446		
Trifluoride															
Nitrogen Tetroxide	352		336		378	183	283	346	355	351	355	346	353	349	341
Perchloryl Fluoride	295	289	285			267		300							
Oxygen Difluoride													442		
Chlorine Pentafluoride	454	421	397	426	387				452	427	442	397	447		
Ozone	395				390										
Moxy 2	492	368	355	374	344				387	373	382	353			
Compound "T" - N_2O_4	467														

* $\frac{1}{2}$ mole N_2O_4 per mole Cmpd "T"

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SUMMARY OF MAXIMUM THEORETICAL DENSITY IMPULSE (Cont.)

(1000/14.7 psia)

(Shifting Equilibrium)

	$N_2H_4-AI-33$	$N_2H_4-AI-43$	$N_2H_4-Be-25$	$N_2H_4-Be-35$	$N_2H_4-Be-45$	$N_2H_4-AIH_3-25$	$N_2H_4-AIH_3-35$	$N_2H_4-AIH_3-45$	$NMH-BeH_2-45$
Oxygen	385	402							342
Hydrogen Peroxide	405	425	410	428	434	387	394	402	340
Chlorine Trifluoride	477	489	496	507	517	474	482	488	462
Nitrogen Tetroxide	403	421	405	411	414	482	391	399	375
Chlorine Pentafluoride	491	499	500	515	523	480	492	498	468
Moxy 2	414								

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VI. THEORETICAL PERFORMANCE DATA

for

FUELS WITH VARIOUS OXIDIZERS

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* $\frac{1}{2}$ mole N O. per mole Compound

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Material A4	Shift's Isp 1000/SL	C ⁺	T _c ^o F	M.R. O/F	Bulk Sp.Gr.	Max IspD 1000/SL	Max IspD O/F	Frozen Isp 1000/SL	Shift's Isp 1000/Vac	A _e /A _t Vac.
Oxygen ^a	(27) 329	6450	6188	1.41	0.942	317	1.86			
Oxygen ^b	(27) 324	6390	6390	1.60	0.955	313	1.94		389	40.0
Hydrogen Peroxide ^a	(27) 310		3780	1.00	0.994	366	4.88			
Hydrogen Peroxide ^b	(27) 305	6000	3753	1.06	1.01	369	5.90		362	40.0
Chlorine Trifluoride ^a	(27) 287	5630	6629	4.26	1.47					
Chlorine Trifluoride ^b	(27) 286	5545	6300	5.06	1.51	446	7.33		342	40.0
Nitrogen Tetroxide ^a	(27) 310		4316	0.724	0.948	358	3.17			
Nitrogen Tetroxide ^b	(27) 302	5890	4212	0.709	0.945	353	3.17		362	40.0
Oxygen Difluoride ^a	(27) 351	6937	7677	3.08	1.23	444	4.56			
Oxygen Difluoride ^b	(27) 349	6900	7720	3.26	1.24	442	4.56		415	40.0
Chlorine Pentafluoride ^a	(27) 304	5995	7209	4.56	1.44	452	7.0			
Chlorine Pentafluoride ^b	(27) 302	5945	7065	4.41	1.43	447	7.33		361	40.0
Nitroxy 2	(27) 312	6185	7272	5.90	1.20					
^a Heat of Formation of A4 = -16.5										
^b Heat of Formation of A4 = -43										

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Hydrazine-Be- (25, 35, 45)	Shift's Isp 1000/SL	C*	T _c °F	M.R. O/F	Bulk Sp.Gr.	Max IspD 1000/SL	Max IspD O/F	Fromen Isp 1000/SL	Shift's Isp 1000/SL	A/A Vac.
25/Hydrogen Peroxide (27)	333	6380	5230	0.49	1.22	410	0.67		398	40.0
25/Chlorine Trifluoride (27)	304	6015	7160	2.85	1.61	496	3.76		360	40.0
25/Nitrogen Tetroxide (27)	325	6280	5985	0.67	1.25	405	0.74		392	40.0
25/Compound "A" (27)	320	6310	7055	1.94	1.50	500	4.00		382	40.0
35/Hydrogen Peroxide (27)	332	6378	5895	0.67	1.29	428	0.70		403	40.0
35/Chlorine Trifluoride (27)	303	5980	7390	3.08	1.65	507	4.13		364	40.0
35/Nitrogen Tetroxide (27)	315	6065	6390	0.85	1.31	411	0.91		381	40.0
35/Compound "A" (27)	317	6105	7898	3.00	1.60	515	4.13		381	40.0
45/Hydrogen Peroxide (27)	323	6205	6200	0.84	1.34	434	0.91		392	40.0
45/Chlorine Trifluoride (27)	305	6050	7590	3.26	1.69	517	3.55		365	40.0
45/Nitrogen Tetroxide (27)	304	5910	6505	1.11	1.36	414	1.17		370	40.0
45/Compound "A" (27)	317	6250	8100	3.44	1.64	523	4.00		381	40.0
wt loading/oxidizer										

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Hydrazine-AlH ₃ (25, 35, 45)	Shift's lap 1000/SL	C*	T _c °F	M.R. O/P	Bulk Sp. Gr.	Max lapD 1000/SL	Max lapD O/P	Freeze lap 1000/SL	Shift's lap 1000/Vac	A/A _c Vac.
25/Hydrogen Peroxide (27)	299	5975	5063	1.27	1.26	387	2.33		352	40.0
25/Chlorine Trifluoride (27)	296	5950	6921	2.85	1.58	474	3.55		348	40.0
25/Nitrogen Tetroxide (27)	305	6085	5648	0.09	1.23	482	1.44		360	40.0
25/Compound "A" (27)	313	6280	7227	2.57	1.52	480	3.17		369	40.0
35/Hydrogen Peroxide (27)	307	6100	4581	0.49	1.21	394	2.33		360	40.0
35/Chlorine Trifluoride (27)	295	5922	6984	2.77	1.59	482	3.76		349	40.0
35/Nitrogen Tetroxide (27)	312	6220	5202	0.49	1.21	391	1.27		367	40.0
35/Compound "A" (27)	313	6240	7668	3.00	1.56	492	3.55		364	40.0
45/Hydrogen Peroxide (27)	316	6255	4878	0.42	1.23	402	1.90		373	40.0
45/Chlorine Trifluoride (27)	295	5880	7173	3.00	1.62	488	4.13		349	40.0
45/Nitrogen Tetroxide (27)	316	6240	5724	0.61	1.25	399	0.89		376	40.0
45/Compound "A" (27)	312	6235	7650	3.26	1.59	498	3.76		365	40.0
wt loading/oxidizer										

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VII. THEORETICAL PERFORMANCE DATA

for

OXIDIZERS WITH VARIOUS FUELS

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		Shift's Isp 1000/ST	C*	T _c ^o F	M.R. O/F	Bulk Sp.Gr.	Max IspD 1000/ST	Max IspD O/F	Proven Isp 1000/ST	Shift's Isp 1000/Vac	A/A _t Vac.
Hydrogen Peroxide											
Hydrazine	(23)	286	5660	4800	2.03	1.26	363	2.12	279	337	39.7
Monomethyl Hydrazine	(26)	285	5665	4930	3.44	1.26			278		
Uns. Dimethyl Hydrazine	(23)	283	5520	4960	4.26	1.25	354	4.56	274	337	45.1
50/50	(27)	283	5710	4840	2.77	1.24	354	3.55			
Hydrogen	(23)	322	6570	3870	7.34	0.435	209	15.7	322	373	34.6
Ammonia	(27)	263	5325	3940	2.77	1.12	302	3.35			
Pentaborane	(23)	316	6210	5660	2.70	1.06	361	5.66	309	375	61.1
Diborane	(24)	334		4725	1.94	0.809					
MHP-1	(27)	278	5620	4795	1.67	1.29	361	1.99			
MHP-3	(27)	281	5665	4805	2.77	1.25	359	3.35			
MHP-5	(27)	284	5670	4875	2.28	1.28	365	2.70			
MHP-1	(27)	281	5560	4995	4.56	1.29	360	5.06			
Hybaline A4 ^a	(27)	310		3780	1.00	0.994	366	4.88			
Hybaline A4 ^b	(27)	305	6000	3755	1.06	1.01	369	5.90		362	40.0
Hybaline A5 ^a	(8)	316	6435	4320	1.00	0.98					
Hybaline A5 ^b	(27)	309	6635	3810	1.02	0.98					
^a Heat of Formation = -16.5											
^b Heat of Formation = -43											

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Chlorine Trifluoride		Shift ^a g 1000/ST.	C*	T _c ^o	M.R. O/Y	Bulk Sp.Gr.	Max LapD 1000/ST.	Max LapD O/Y	Process Lap 1000/ST.	Shift ^a g 1000/ST.	Δ/A °C Vac.
Hydrazine	(23)	293	5810	6530	2.70	1.48	436	2.70	278	337	32.8
Monomethyl Hydrazine	(24)	283		6105	2.84	1.42	282	3.17			
Uns. Dimethyl Hydrazine	(23)	280	5520	6370	3.00	1.37	385	3.17	269	323	40.9
50/50	(27)	283	5705	5884	2.57	1.44	414	3.65			
Hydrogen	(23)	318	6440	5670	11.5	0.610	289	27.6	299	364	30.9
Pentaborane	(23)	290	5550	7620	7.33	1.47	446	11.5	268	350	52.5
MHF-3	(27)	282		5769	2.39	1.42	411	3.76			
MHF-5	(27)	285		6226	2.51	1.51	431	3.00			
MAP-1	(27)	270	5380	5742	2.45	1.41	387	5.67			
Hybeline A4 ^a	(27)	287	5630	6629	4.26	1.47					
Hybeline A4 ^b	(27)	286	5545	6300	5.06	1.51	446	7.33		342	40.0
Hydrazine-Al-53	(27)	290		7220	2.51	1.65	477	2.57			
Hydrazine-Al-43	(27)	287	5710	7525	2.64	1.71	489	2.70			
Hydrazine-Re-25	(27)	304	6015	7160	2.85	1.61	496	3.76		360	40.0
Hydrazine-Be-35	(27)	303	5980	7390	3.08	1.65	507	4.13		364	40.0
Hydrazine-Be-45	(27)	305	6050	7590	3.26	1.69	517	3.55		365	40.0
^a Heat of Formation = -16.5											
^b Heat of Formation = -43											

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Nitrogen Tetroxide		C*	T _c ^o F	M.R. O/P	Bulk Sp.Gr.	Max LapD 1000/SL	Max LapD O/P	Frozen Lap 1000/SL	Shift's Lap 1000/SL	h _o /A _c vac.
Hydrazine	(23)	5610	5410	1.32	1.21	352	1.38	280	342	39.0
Monomethyl Hydrazine	(24)		5645	1.49	1.19					
Uns. Dimethyl Hydrazine	(23)	5520	5720	2.57	1.16	336	2.86	271	316	35.7
50/50	(26)	5740	5610	2.00	1.21			275		
RP-1	(27)	5420	4940	6.41	1.30	378	7.34	269	229	43.6
Hydrogen	(23)	6980	4330	5.25	0.352	183	11.5	339	396	34.9
Ammonia	(27)	5350	4495	2.03	1.06	283	2.23			
Pentaborane	(23)	5890	7220	3.35	1.10	346	4.00	293	369	52.5
Diborane	(24)		6615	3.16	0.925					
MEF-1	(27)	5680	5360	1.15	1.25	355	1.33			
MEF-3	(27)	5705	5571	2.03	1.21	351	2.23			
MEF-5	(27)	5725	5465	1.44	1.23	355	1.67			
NAP-1	(27)	5610	5740	2.64	1.23	346	3.00			
Hybaline A4 ^a	(27)		4315	0.724	0.948	358	3.17			
Hybaline A4 ^b	(27)	5890	4210	0.709	0.945	353	3.17		362	40.0
Hybaline A5 ^a	(27)		4385	0.667	0.917	354	3.26			
Hybaline A5 ^b	(27)	5955	4310	0.695	0.922	349	3.35		366	40.0
^a Heat of Formation = -16.5 ^b Heat of Formation = -43										

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a Heat of Formation = -16.5

b Heat of Formation = -43

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VIII. LIQUID PROPELLANT REFERENCES

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LIQUID PROPELLANT REFERENCES

- *1. "Liquid Propellant Handbook," Battelle Memorial Institute, 1955-1957. (Confidential)
- *2. JANAF Thermochemical Data, "JANAF Heat of Formation of Propellant Ingredients (U)," 1963-1964. (Confidential)
- *3. AFRL Computer Data File.
- 4. "Diborane, Space Storable Fuel," Callery Chemical Co., January 1962.
- 5. "Design Handbook for Oxygen Difluoride," Donald F. Sekets, ATD-TDR-63-1084, Contract AF 04(611)-8400, Thiokol Chemical Co., Reaction Motors Division. (Confidential)
- *6. "Hybaline Liquid Rocket Fuels - Technical Information," Union Carbide Corporation, 1 November 1964. (Confidential)
- 7. "The Handling and Storage of Liquid Propellants," AFM 160-39, 1 April 1964.
- *8. "Research and Development of Metal Hydride Organic Nitrogen Complexes," Final Report, 3 Volumes, Union Carbide Corporation, 1 November 1964. (Confidential)
- 9. "Handbook of Astronautical Engineering," Heinz Hermann Koelle, McGraw-Hill Book Co., 1961.
- 10. "Storable Liquid Propellants," 2nd Ed., Report No. LRP 198, Aerojet-General Corp., June 1962.
- 11. "Storable Liquid Propellants," Revision A, Aerojet-General Corporation, October 1960.
- 12. "Liquid Propellant Manual," Liquid Propellant Information Agency, 1961. (Confidential)
- *13. "Solid Rocket Propellant Research and Development (U)," Annual Report, Jan-Dec 1962, Contract NOrd 18728, American Cyanamid Co. (Confidential)
- *14. "Solid Rocket Propellant Research and Development (U)," Progress Report No. 16, April-June 1964, Contract NOrd 18728, American Cyanamid Co. (Confidential)
- 15. "Chemical Safety Data Sheet SD-84 - Boron Hydrides," Manufacturing Chemists Association, 1961.

*Classified information has been extracted from documents listed under References marked with an asterisk.

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16. "Pentaborane," Technical Bulletin CT-1300, Production Information, Callery Chemical Co., 1 October 1961.
- *17. "Chemical Research as Related to Advanced Solid Propellants (U)," Report No. 19 (Final Report), Jan to Dec 1963, Contract NOrd 18688, Minnesota Mining and Manufacturing Co. (Confidential)
18. "Tetrafluorohydrazine," Liquid Propellant Information Agency Unit, 6 July 1962.
- *19. "Preparation and Characterization of a New High-Energy Oxidizer (U)," Final Report, Contract AF 04(611)-9563, Rocketdyne, January 1965. (Confidential)
- *20. "Evaluation of a High Energy Liquid Propellant Rocket Engine Oxidizer and a Pilot Production of Same (U)," Final Report, Contract AF 04(611)-8182, Minnesota Mining and Manufacturing Co, April 1965. (Confidential)
- *21. "Interhalogen Oxidizers and Hydrazine Fuels for Packaged Liquid Power Plants," TPR 120-64, Thiokol Chemical Co., Reaction Motors Division, January 1964. (Confidential)
- *22. "Packaged Liquid Propulsion Symposium," CPIA Publication No. 13, Bureau of Naval Weapons, March 1963. (Confidential)
23. "Thermodynamics of Rocket Propulsion and Theoretical Evaluation of Some Prototype Propellant Combinations," Thomas O. Dobbins, WADC TR-59-757, December 1959.
24. "Propellant Performance Data," Callery Chemical Co., 1961.
25. "Theoretical Liquid Propellant Performance Calculations (U)," Donald G. Nyberg, NAVWEPS report 8588, NOTS TR 3597, U.S. Naval Ordnance Test Station, October 1964. (Confidential)
26. "Theoretical Performance of Rocket Propellant Combinations," Publication 573-A-2 Rev. 3-64, Rocketdyne.
- *27. AFRPL (RPCL) Computer program,
- *28. "Proceedings of the Metallized Gelled Propellants Conference," Air Force Rocket Propulsion Laboratory, 10-12 June 1963. (Confidential)
- *29. "2nd metallized Gelled Propellants Conference," Air Force Rocket Propulsion Laboratory, 26-28 August 1964, CPIA Publication No. 64, November 1964. (Confidential)
- *30. "Investigation of a High-Energy Monopropellant," Annual Summary Report, Rocket Research Corp, AFRPL-TR-65-18, April 1965. (Confidential)

*Classified information has been extracted from documents listed under References marked with an asterisk.

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IX. SOLID PROPELLANT PROPERTIES

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FUELS

<u>Formula</u>	<u>Name</u>	<u>Abbreviation</u>	<u>Density</u>	<u>(Ref)</u>	<u>Heat of Formation</u>	<u>(Ref)</u>
Al (s)	Aluminum	LM-1	2.7	(1)	0.0	(1)
AlH ₃ (s) (Form 1451)	Aluminum Hydride	LMH-1	1.4	(7)	-2.2 ± 1 -2.77 ± .1	(7)
Be (s)	Beryllium	LM-2	1.85	(1)	0	(1)
BeH ₂ (s)	Beryllium Hydride	LMH-2	0.38	(2)	-4.5	(2)
Be ^{8.6542^F} 17.6277 ^C 0.3522 (93%)			.66	(12)	-53.6	(12)
Be ^{1.00^H} 2.0356 ^O 0.008 ^C 0.0278					-5.576	(12)
B (s)	Boron		2.32	(1)	9.0	(1)
B ₁₀ H ₁₄ (s)			0.94	(1)	-15.8	(1)
C ₁₀ H ₂₀ (1)	Decaborane		0.804	(1)	-173.3	(1)
C _{9.657^H18.87 (1)}		UP-4	0.77	(1)	-54.8	(1)
Li (s)	Lithium		0.534	(1)	0.0	(1)
LiH (s)	Lithium Hydride		0.820	(1)	-21.6	(1)
LiAlH ₄ (s)	Lithium Aluminum Hydride		0.93	(1)	-24.1 -26.63 ± .311	(1) (21)
LiBH ₄ (s)	Lithium Borohydride		0.66	(1)	-46.44	(1)

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<u>Formula</u>	<u>Name</u>	<u>Abbreviation</u>	<u>Density</u>	<u>(Ref)</u>	<u>Heat of Formation</u>	<u>(Ref)</u>
Mg (s)	Magnesium		1.74	(1)	0.0	(1)
MgH ₂ (s)	Magnesium Hydride		1.45	(1)	-17	(1)
Na	Sodium		0.97	(1)	0.0	(1)
NaH	Sodium Hydride		---		-13.7	(2)
Pb (s)	Lead		11.337	(1)	0.0	(1)
S (s)	Sulphur		2.046	(1)	0.0	(1)
Si (s)	Silicon		2.4	(1)	0.0	(1)
SiH ₄ (l)	Silicon Hydride		0.68 @ 162	(1)	6.4 @ 162	(1)
Ti (s)	Titanium		4.5	(1)	0.0	(1)
Zr	Zirconium		6.4	(1)	0.0	(1)
B ₁₀ H ₁₀ C ₂ H ₂	Carborane		---		-27.6	(4)
(CH ₃) ₄ NB ₃ H ₈	Tetramethyl ammonium triborohydride		---		-22	(6)
Mg(AlH ₄) ₂	Magnesium Aluminum Hydride		---		-31.5±6	(7)
LiAlH ₄ ·5AlH ₃			---		-64	(8)
LiAlH ₄ ·10AlH ₃			---		-64	(8)
ZrSi			---		-18	(8)

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<u>Formula</u>	<u>Name</u>	<u>Abbreviation</u>	<u>Density</u>	<u>(Ref)</u>	<u>Heat of Formation</u>	<u>(Ref)</u>
ZrSi ₂			---		-12	(8)
C ₁₇ H ₂₀ ON ₂	Ethyl Centralite		---		-34.2	(10)
C ₆ H ₈ ON ₂	Adiponitrile		---		+26.3	(10)
Al(B ₂ H ₅) ₃	Aluminum Triborohydride		0.5	(11)	-75	(11)
Al(BH ₄) ₃ ·CH ₂ O	Aluminum Borohydride Polymethylene Oxide		1.80	(11)	-132	(11)
Al(BH ₄) ₃ ·2C ₂ H ₄ O	Aluminum Borohydride: Polyethylene Oxide		0.71	(11)	-177.4	(11)
Be(BH ₄) ₂	Beryllium Borohydride		---		-25.8	(7)
Al(BH ₄) ₃	Aluminum Borohydride		0.57	(5)	+2.5	(7)
Zr(BH ₄) ₄ ·CH ₃ NH ₂			---		-34.2	(13)
LiAl			---		-15	(8)
Li ₂ BeH ₄			0.703	(12)	-79.9	(12)
LiBeH ₃			---		-42.2	(12)

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<u>Formula</u>	<u>Name</u>	<u>Abbreviation</u>	<u>Density</u>	<u>Heat of Formation</u>	<u>(Ref)</u>
$C_{10}H_{22}$	Isodecane		0.728	-73.1	(20)
$PbC_{36}H_{70}O_4$	Lead Stearate	PbSt	0.9	-424	(20)
$(N_2H_5)_2B_{10}H_{10}$	Dihydrazinium Perhydrodecaborate	H_2D	---	-48.3±4.7	(6)
$(CP_3)_4NB_3H_8$	Tetramethyl Ammonium Hydrotriborate	QMB3	---	-40. ±1.5	(5)
$(C_2H_5)_4NB_3H_8$	Tetraethyl Ammonium Hydrotriborate	QEB3	---	-59.0±3.0	(5)
AlH_3	Olane 58		---	-4.6±1.6	(21)
AlH_3	Dowane 1451		---	-2.53±1.6	(21)
$L_4_3AlH_6$			---	-79.4 ±3.4	(21)
NH_4CN	Ammonium Cyanide		0.79	-0.7	(14)

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OXIDIZERS

<u>Formula</u>	<u>Name</u>	<u>Abbreviation</u>	<u>Density</u>	<u>Heat of Formulation</u>	<u>(Ref)</u>
NF_3 (l)	Nitrogen Trifluoride		1.532 @ 144°C (1)	-328.144°C	(1)
NH_4NO_3 (s)	Ammonium Nitrate	AN	1.725 (1)	-87.27	(1)
NH_4ClO_4 (s)	Ammonium Perchlorate	AP	1.96 (1)	-70.7	(20)
NO_2ClO_4 (s)	Nitronium Perchlorate	NP	2.22 (1)	8.0	(1)
$\text{N}_2\text{H}_5\text{NO}_3$ (s)	Hydrazinium Nitrate		1.685 (1)	-59	(1)
LiClO_4 (s)	Lithium Perchlorate		2.43 (1)	-92.0 -90.88	(1) (20)
H_2O 1.5836 @ 0.4197 (g)	Air		---	0.0	(1)
NE_2OH	Hydroxylamine		---	-25.5	(2)
NH_4NO_2	Ammonium Nitrite		---	-63.1	(2)
$\text{NH}_2\text{OH} \cdot \text{NO}_3$	Hydroxylammonium Nitrate		---	-86.3	(2)
$\text{CF}(\text{NO}_2)_3$		D-11	1.502 (3)	-37.3	(3)
$\text{C}_2\text{F}_2(\text{NO}_2)_4$		D-112	1.702 (3)	-90.5	(3)
$\text{N}_2\text{H}_5\text{C}(\text{NO}_2)_3$		HNF	1.85 (4)	-17	(4)
$\text{N}_2\text{H}_5\text{ClO}_4$ (s)	Hydrazinium Perchlorate		---	-40.4	(1)

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<u>Formula</u>	<u>Names</u>	<u>Abbreviation</u>	<u>Density</u>	<u>(Ref)</u>	<u>Heat of Formation</u>	<u>(Ref)</u>
$C_2(NO_2)_6$	Hexanitro Ethane	HNE	1.81	(4)	+24.1	(4)
$(LiClO_4)_6 NO_2 ClO_4$			2.29	(4)	-50	(4)
$(NO_2)_3 Al(ClO_4)_6$			2.35	(4)	-120	(4)
$[(NO_2)_3 CCH_2]_2 NNO_2$		BTNEN	1.96	(4)	+6	(4)
$C_3H_5O_9N_3$	Nitroglycerine	NG	1.60	(4)	-89.1 -82 -90.75	(20) (4) (7)
$HC(NO_2)_3$	Nitroform		1.60	(4)	-18.6	(4)
$C(NO_2)_4$	Tetranitro Methane	TNM	1.65 1.64	(4) (3)	+8.8 +10.3	(4) (3)
$C_5H_9O_{10}N_3$	"Petrin"		1.60	(4)	-133	(4)
$C_4H_8HgO_8$	Cyclotetramethylene Tetranitramine	HMX	1.90	(4)	-17.92 +11	(4) (7)(8)
$C_2H_4(NF_2)_2$			---		-46.6 -38	(4) (5)
$CH_3CH(NF_2)CH_2(NF_2)$			---		-40.1	(5)
$CH_2(NF_2)CH(NF_2)CH_2(NF_2)$			1.503	(4)	-71.8	(4)
$CH_3CH(NF_2)CH(NF_2)CH_3$			1.226	(4)	-67.6 -58.8	(4) (4)

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<u>Formula</u>	<u>Name</u>	<u>Abbreviation</u>	<u>Density</u>	<u>(Ref)</u>	<u>Heat of Formation</u>	<u>(Ref)</u>
$C_4H_6(NF_2)_4$			1.54	(4)	-93.4	(4)
$C_4H_5(NF_2)_5$			---		-109.4	(4)
$C_4H_4(NF_2)_6$	Tetrakis (DA) Tetrahydrofuran		1.604	(4)	-108.0	(4)
$C_4H_3(NF_2)_7$	Pentakis (DA) Tetrahydrofuran		1.65	(4)	-124.0	(4)
$C_4H_2(NF_2)_8$	Hexakis (DA) Tetrahydrofuran		---		-125.4	(4)
$C_4H_2(NF_2)_8$	Octakis (DA) Tetrahydrofuran		---		-140.6	(4)
$C_4(NF_2)_8$	Hexakis (DA) B_2		---		-172	(4)
$C_6H_7(NF_2)_5$	Pentakis (DA) Cyclohexane		1.82	(4)	-22.2	(4)
$C_6H_6(NF_2)_6$	Hexakis (DA) Cyclohexane		1.746	(4)	-111.5	(4)
$C_6(NF_2)_6$	Hexakis (DA) Cyclohexane		1.75	(4)	-127.2	(4)
$C_6(NF_2)_{12}$	Tetrakis (DA) Tetrahydrofuryl urea		1.97	(4)	-221.29	(4)
$O-C[NF_2C_4H_3(NF_2)_4O]$			---		-347.15	(4)

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<u>Formula</u>	<u>Name</u>	<u>Abbreviation</u>	<u>Density</u>	<u>(Ref)</u>	<u>Heat of Formation</u>	<u>(Ref)</u>
$[C_5H_4(NF_2)_5]_2$			---		-161	(4)
HF_3OHCIO_4	Hydroxyl Ammonium Perchlorate		---		-68	(8)
$CN_2H_6C(NO_2)_3$	Guanidine Nitroform		---		-48	(8)
$HNCF_2$			1.42(80°C)	(9)	-10	(9)
O_2F_2			1.95	(9)	+ 6.6	(9)
$C_2H_2N_4O_9$		TNEN	---		-22.6	(10)
$C_5H_8N_6F_8O$		DEI-UREA			-44.0	(10)
$C_5H_7N_3O_2F_4$		PVA-DEI	1.1	(20)	-124 -93.3	(20) (10)
$C_4H_6N_4F_8$		TDB	---		-93.3	(10)
CN_3F_7		R	1.8	(11)	-75±5 -43.3±1	(11) (7)
$Cr_6H_8 \cdot HClO_4$	Triamino Guanidinium Perchlorate		1.55	(11)	15	(11)
$NO_2B(CIO_4)_4$			---		-83±5	(5)
$NO_2B(CIO_4)_4$			---		-125 to -150	(5)

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<u>Formula</u>	<u>Name</u>	<u>Abbreviation</u>	<u>Density</u>	<u>(Ref)</u>	<u>Heat of Formation</u>	<u>(Ref)</u>
$C_4H_4F_8$ (1)	Tetraakis Difluoramino Tetrahydrofuran		---		-82	(8)
CF_3F_5 (g)	Perfluoroguanidine	PFG	---		+34±10	(7)
$C_4H_6O_6N_4F_4$	3,4 bis (DA)-1,2 butanediol dinitrate		1.59	(10)	-82	(10)
$C_2H_4[CH_2C(NO_2)_2]_2$	Ethylene Diamine Dinitroform		---		-68	(8)
$PBC[CH_3C(NO_2)_2]_2$	Guanidine Dinitroform		---		-76	(8)
$C_6H_{16}N_4[C(NO_2)_2]_4$	Hexamethylene Tetramine Tetranitroform		---		-71	(8)
$N_2H_4[C(NO_2)_2]_2$	Hydrazine Dinitroform		---		-31	(8)
$HOCH_2C(NO_2)_2$	Hydroxylamine Nitroform		---		-44	(8)
$N_2H_5(ClO_4)_2$	Hydrazine Diperochlorate		---		-72	(8)
$(NO_3)N_2H_5C(NO_2)_2$	Hydrazine Nitroform Nitrate		---		-69	(8)
$CH_3NH_3C(NO_2)_2$	Methylamine Nitroform		---		-50	(8)
$[C(CH_3)_2C(NO_2)_2]_n$	MMH Nitroform		---		-21	(8)

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<u>Formula</u>	<u>Name</u>	<u>Abbreviation</u>	<u>Density</u>	<u>(Ref)</u>	<u>Heat of Formation</u>	<u>(Ref)</u>
NH_4NO_3	TAG Dinitroform		---		+6	(8)
HClO_4 (1)	Perchloric Acid		---		- 11.1	(2)
NH_4NO_2	TAG Nitroform		---		+27	(8)
N_2O_5	Dinitrogen Pentoxide		---		-10.6	(14)
CH_3NF_2 (R)			---		-20.5±2.0	(7)
$\text{CF}_2(\text{OF})_2$ (g)		RDX	1.816	(20)	-130 ± 3	(7)
$\text{C}_3\text{N}_3\text{H}_6(\text{NO}_2)_3$					16.1	(20)
$\text{C}_5\text{H}_9\text{O}_9\text{N}_3$		TMETN	1.488	(20)	-105	(20)
$\text{CF}_2(\text{OF})_2$ (g)			---		-130.7± 1	(7)
$\text{CF}_2(\text{NF}_2)_2$ (g)			---		-103.7± 1	(7)
$\text{C}_2\text{F}_{11}\text{N}_5$ (1)		F11BG	---		-83.5±2.9	(7)
FCIO_4 (g)	Fluorine Perchlorate		---		+37.6± 9	(17)
FNO_3 (g)	Fluorine Nitrate		---		+2.5±0.6	(17)
NO_2F			---		-25.8	(17)
$\text{C}_4\text{H}_6\text{N}_4\text{O}_{11}$		NIENG	1.65	(18)	-86.4	(18)
$\text{I}_3\text{COCH}_2\text{CH}_2\text{OCl}_3$		EGA	---		-73.7	(10)
$\text{I}_3\text{COCH}_2\text{CH}_2\text{CH}_2\text{OCl}_3$		FACD	---		-91.1	(10)

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<u>Formula</u>	<u>Name</u>	<u>Abbreviation</u>	<u>Density</u>	<u>(Ref)</u>	<u>Heat of Formation</u>	<u>(Ref)</u>
$X_3CHCO-NHCHCOCHX_3$		HTBU	---		-86.5	(10)
$X_3CHCHCOCHX_3$		HDM-UREA	---		-46.9	(10)
$C_6H_{11}O_3N_9$	Hexametriol Trinitrate	HTT	1.405	(20)	-124.6	(20)
$CH_4O_2N_4$	Nitroguanidine	HBNQ	1.69	(20)	-21.6	(20)
$C_{12}H_{10}O_2N_2$	Nitrodiphenylamine	2-NDPA	1.366	(20)	+17.82	(20)
C_3H_3N	Polyacrylonitrile		1.13	(20)	+28.27	(20)
C_3H_5ON	Polyacrylamide		1.122	(20)	-67	(20)
$C_{535}H_{731}O_5.373$ $N_{856}Cl_{1.0}$	NP - Chlorostyrene		2.0	(20)	+ 6.82	(20)
$C_{1.601}H_{.779}O_5.333$ $N_{1.0}Cl_{.889}$	NP - Cyanostyrene		2.12	(20)	+12.06	(20)
$C_{.683}H_{.512}O_5.487$ $N_{.915}Cl_{1.085}$	NP - Dichloro-styrene		2.06	(20)	+7.43	(20)
$C_{1.075}H_{1.075}O_5.194$ $N_{.866}Cl_{.866}$	NP - Styrene		1.93	(20)	+8.13	(20)
$C_2H_4N_6O_8$	NNNN'TetraNitro Ethylene Diamine	TNEDA	1.75		+55.9	(9)
N_2O_5 (g)			1.63	(14)	-10.0	(14)

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BINDERS

<u>Formula</u>	<u>Names</u>	<u>Abbreviation</u>	<u>Density</u>	<u>(Ref)</u>	<u>Heat of Formation</u>	<u>(Ref)</u>
CH_2 (s)	Polyethylene	PE	.92	(1)	-6.5	(1)
C_2F_4 (s)	Teflon		2.1	(1)	-193.5	(1)
$\text{C}_{5.3614}\text{H}_{9.8716}\text{O}$ 1.4016		POLYU	1.01	(1)	-75.24	(1)
NO 1.19						
$\text{C}_{5.117}\text{H}_{9.586}\text{O}$ 1.684		POLYU			-82.8	(20)
NO 1.38						
$\text{C}_{11}\text{F}_{14}\text{H}_8$ (s)		VITON	1.85	(1)	-726.7	(1)
$\text{C}_{2.53}\text{H}_{4.10}\text{N}$ 1.64 2.66	Nitro Polyurethane	NPU	1.5	(4)	-16.7	(4)
$(\text{C}_2\text{N}_2)_x$	Paracyanogen		---		+55	(4)
CHNO_2			1.6	(4)	0.0	(4)
$\text{C}_6\text{H}_7.55\text{O}_9\text{N}^{2.55}_x$	Nitrocellulose	NC	1.66	(4)	-170.2	(14)
$[\text{C}_9\text{H}_6(\text{NF}_2)_2]_x$	Difluoraminobutadiene	DBPB	1.45	(4)	-54.4	(4)
$\text{C}_4\text{H}_6\text{F}_{13}\text{N}_2$ 2.6			1.39	(20)	-35.3	(20)

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<u>Formula</u>	<u>Name</u>	<u>Abbreviation</u>	<u>Density</u>	<u>(Ref)</u>	<u>Heat of Formation</u>	<u>(Ref)</u>
$C_2H_3OOCCH_4H_3(NF_2)_4O$			---		-187	(4)
$C_2H_3OOCCH_4H(NF_2)_6O$			---		-216	(4)
$(CHNF_2)_x$			1.65	(4)	-21.45	(4)
$C_{11}H_8F_{14}$	(Fluorel Polymer)		1.80	(4)	-760.4	(4)
$(CH_2CH_2NHF_2)_x$		FEH	---		+4	(6)
CH_3F_5	Polyperfluoro-guanidine		1.93	(11)	-24.5 (est)	(11)
CH_2F_4	Polyperfluoro-formamidine		1.87	(11)	-62.6 (est)	(11)
$C_3H_6F_{12}$	Perfluoromelamine		1.6	(11)	-168.84 (est)	(11)
C_3F_7NO	$(C_2F_4-CF_3NO)$ Copolymer		1.82	(11)	-351 (est)	(11)
$C_{1.132}H_{5.952}N_{5.718}$	Polytriiminoguanidine Azide	Poly Taz II	---		+65.3	(7)
$C_8.9535H_{10.3873}O_{.1614}N_{.0042}P_{.0014}S_{.6158}$		PPAA	0.927	(20)	-17.68	(20)

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<u>Formula</u>	<u>Name</u>	<u>Abbreviation</u>	<u>Density</u>	<u>(Ref)</u>	<u>Heat of Formation</u>	<u>(Ref)</u>
$C_{10}H_{16}O_5$		HX-730	1.4	(20)	-45.24	(20)
$C_{11}H_{12}O_5$		DB	1.4	(20)	-45.24	(20)
$C_{13}H_{14}O_5$		E107	1.05	(20)	-1369.1	(20)
$C_{11}H_{12}O_5$		ESTANE 5830101	1.0	(20)	-2194.8	(20)
$C_{11}H_{10}N_2F_4$	Nitrocellulose Difluoramine Ethyl Isocyanate	NCDEL	1.1	(20)	-274	(20)
$C_{21}H_{34}O_5$		NCMETN	1.48	(20)	-52.62	(20)
$C_{21}H_{34}O_5$	(Nitro-polymer)		1.4	(20)	-7.95	(20)
$C_{17}H_{22}O_5$	Polyglycol dipate- Oxamide 511	PGAO	1.243	(20)	-207.7	(20)
$C_{21}H_{34}O_5$	KEL-F		---		-51.4	(20)
$C_{18}H_{22}O_5$		DB(VCF)	1.57	(23)	-50.65(calc)	(23)
$C_{21}H_{34}O_5$		DB(BARC)	1.49	(23)	-46 (calc)	(23)

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ADDITIVES

Formula	Names	Abbreviation	Density	(Ref)	Heat of Formation	(Ref)
He (1)	Helium		0.1251	(1)	-1.48	(1)
$N_2H_4(BH_3)_2$	Hydrazine bis-Borane	HRB	0.86	(4)	-30	(4)
$N_2H_2(BH_2)_2$		HoBB	1.15	(4)	-49	(4)
$N_2H_4(BH_3)_2$	Hydrazine Triborohydride		---		-10	(4)
$N_2H_4(BH_3)_2$.955	(4)	-10	(4)
$B_{10}H_{14}(NH_3)_2$	Dekazene		1.06	(16)	-104	(4)
$B_{10}H_{12}(NH_3)_2$			---		-66.6	(16)
$(CH_3)_2N_2(BH_3)_2$			---		-49	(4)
$(CH_3)_6B_{10}H_{10}$	TAG Decaborane		1.54	(4)	+60	(4)
$(N_2H_5)_2B_{10}H_{12} \cdot N_2H_4$		H_3D	---		-22	(6)
$CH_9N_6B_3H_8$	TAG Triborohydride		---		+47.9	(6)
$(CH_3)_4N_3H_8$	Tetra Methyl Ammonium Triborohydride		---		-33.6	(6)

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<u>Formula</u>	<u>Name</u>	<u>Abbreviation</u>	<u>Density</u>	<u>(Ref)</u>	<u>Heat of Formation</u>	<u>(Ref)</u>
$C_6H_6O_2$	Resorcinol	RES	1.27	(15)	-87.57	(15)
$C_2H_6O_2$	Ethylene Glycol	EG	1.115	(20)	-108.5	(20)
$C_4H_{10}O_2$	1,4 Butanediol		1.02	(20)	-120	(20)
$C_{15}H_{26}O_6$	Tributyrin	TB	1.032	(20)	-357.8	(20)
$C_6H_{15}O_3N$	Triethanolamine	TEA	1.124	(20)	-158.9	(20)
CN_3OCl	Chloronitroform	CLNF	1.7	(20)	-50.01	(20)
$C_{109}H_{149}O_{74}$	Cellulose Acetate		1.4	(20)	-2582.2	(20)
$C_5H_{10}O_6N_2$	1,5 Dinitroxypentane	1,5 DNP	0.9	(20)	-78.34	(20)
$C_5H_{10}O_6N_2$	2,4 Dinitroxypentane	2,4 DNP	0.9	(20)	-85.13	(20)
$C_3H_6O_6N_2$	1,2 Dinitroxyp propane	1,2 DNP	1.2	(20)	-70.56	(20)
$C_{12}H_{14}O_4$	Diethylphthalate	DEP	1.123	(20)	-178.6	(20)
$C_{13}H_{34}O_4$	Di-n-Butyl Debacate	DBS	1.0	(20)	-285.1	(20)
$C_2H_8O_4N_2$	Ammonium Oxalate		1.501	(20)	-286.72	(20)
CH_3ON	Formamide		1.139	(20)	-62.4	(20)
C_3H_5ON	PAM		---		-65	(6)
NH_4BH_3			---		-96.5	(24)

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X. SOLID PROPELLANT THEORETICAL PERFORMANCE

(listed by fuel)

10.0

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ALUMINUM

20% PE / 65% NP / 15% Al

(25)

<u>Isp</u>	<u>T_c</u>	<u>Density</u>	<u>C*</u>	<u>Vac Isp</u>
281 sec	3870°K	1.772 g/cc	5526 ft/sec	355 sec

20% PE / 65% HAP / 15% Al

(25)

<u>Isp</u>	<u>T_c</u>	<u>Density</u>	<u>C*</u>	<u>Vac Isp</u>
263 sec	2930°K	1.699 g/cc	5237 ft/sec	321 sec

15% NC / 30% TMETN / 1% AN / 44% INFO 635 / 10% Al

(25)

<u>Isp</u>	<u>T_c</u>	<u>Density</u>	<u>C*</u>
279 sec	2640°K	1.79 g/cc	5510 ft/sec

NOTE:

All sea level specific impulse values are at 1000 psia chamber pressure expanded to 14.7 psia.

All vacuum specific impulse values are at 1000 psia chamber pressure and an expansion ratio of 40:1.

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BERYLLIUM

25% TMETN / 4% DEGDN / 9.5% PNC / 1.5% TDI / 27.73% AP / 12.27% Be / 20% TAZ
(25)

<u>Isp</u>	<u>T_c</u>	<u>Density</u>	<u>C*</u>
287 sec	3552°K	1.691 g/cc	5631 ft/sec

23.12% TMETN / 2.78% DEGDN / 8.79% NC / 1.85% TDI / 0.46% EC / 29.11% AP /
11.89% Be / 22% THA
(25)

<u>Isp</u>	<u>T_c</u>	<u>Density</u>	<u>C*</u>	<u>Vac Isp</u>
292 sec	3485°K	1.628 g/cc	5650 ft/sec	332 sec

13% NC / 37% TMETN / 33% AP / 17% Be
(6)

<u>Isp</u>	<u>T_c</u>	<u>Density</u>
280 sec	3965°K	1.66 g/cc

9.95% NC / 14.93% TMETN / 16.41% DEGDN / 1.0% TDI / 26.26% AP / 11.55% Be /
19.9% TAZ
(8)

<u>Isp</u>	<u>T_c</u>	<u>Density</u>
9 sec	3481°K	1.62 g/cc

NOTE:

All sea level specific impulse values are at 1000 psia chamber pressure expanded to 14.7 psia.

All vacuum specific impulse values are at 1000 psia chamber pressure and an expansion ratio of 40:1.

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BORON

P-BEP/TVOPA :: 1/1

25% Binder / 50% BTU / 20% AP / 5% Boron

(25)

<u>Isp</u>	<u>T_c</u>	<u>Density</u>	<u>C*</u>	<u>Vac Isp</u>
297 sec	4255°K	1.828 g/cc	5940 ft/sec	366 sec

P-BEP/TMETN :: 1/1

25% Binder / 60% BTU / 10% AP / 5% Boron

(25)

<u>Isp</u>	<u>T_c</u>	<u>Density</u>	<u>C*</u>	<u>Vac Isp</u>
299 sec	4340°K	1.766 g/cc	5981 ft/sec	369 sec

35% P-BEP / 40% BTU / 20% NP / 5% Boron

(25)

<u>Isp</u>	<u>T_c</u>	<u>Density</u>	<u>C*</u>	<u>Vac Isp</u>
300 sec	4408°K	1.807 g/cc	5951 ft/sec	374 sec

70% P-BEP / 25% AP / 5% Boron

(25)

<u>Isp</u>	<u>T_c</u>	<u>Density</u>	<u>C*</u>	<u>Vac Isp</u>
279 sec	3409°K	1.742 g/cc	5568 ft/sec	344 sec

NOTE:

All sea level specific impulse values are at 1000 psia chamber pressure expanded to 14.7 psia.

All vacuum specific impulse values are at 1000 psia chamber pressure and an expansion ratio of 40:1.

10.3

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LF1aIUM

26.7% P-BEP / 14.4% NP / 11.7% LI / 45.2% BTU

(25)

<u>Isp</u>	<u>T_c</u>	<u>Density</u>
308 sec	4561°K	1.40 g/cc

POLYU

75% NP (5% Coat) / 25% POLYU

(25)

<u>Isp</u>	<u>T_c</u>	<u>C*</u>
270 sec	3518°K	5182 ft/sec

NOTE:

All sea level specific impulse values are at 1000 psia chamber pressure expanded to 14.7 psia.

All vacuum specific impulse values are at 1000 psia chamber pressure and an expansion ratio of 40:1.

10.4

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LMH-1

20% PE / 62.5% NP / 17.5% LMH-1

(25)

<u>Isp</u>	<u>T_c</u>	<u>Density</u>	<u>C*</u>	<u>Vac Isp</u>
292 sec	3527°K	1.616 g/cc	5781 ft/sec	361 sec

20% PE / 55% HAP / 25% LMH-1

(25)

<u>Isp</u>	<u>T_c</u>	<u>Density</u>	<u>Vac Isp</u>
272 sec	2423°K	1.53 g/cc	343 sec

8% NC / 24% TEGDN / 50% INFO-635 / 18% LMH-1

(25)

<u>Isp</u>	<u>T_c</u>	<u>Density</u>	<u>C*</u>	<u>Vac Isp</u>
280 sec	3156°K	1.62 g/cc	5545 ft/sec	410 sec

NOTE:

All sea level specific impulse values are at 1000 psia chamber pressure expanded to 14.7 psia.

All vacuum specific impulse values are at 1000 psia chamber pressure and an expansion ratio of 40:1.

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LMH-2

20% P-BEP / 55% AP / 25% LMH-2 (25)

<u>Isp</u>	<u>T_c</u>	<u>Density</u>	<u>C*</u>	<u>vac Isp</u>
321 sec	3290°K	1.28 g/cc	6166 ft/sec	413 sec

10.8% NC / 3.9% DEGDN / 35.1% NIBTN / 35.2% AP / 15% LMH-2 (18)

<u>Isp</u>	<u>T_c</u>	<u>Density</u>
301 sec	3588°K	1.27 g/cc

11.4% NC / 23% TMETN / 22% Plasticizer / 27% AP / 3.2% Be metal / 13.5% LMH-2 (amorphous) (8)

<u>Isp</u>	<u>T_c</u>	<u>Density</u>
304 sec	3453°K	1.36 g/cc

48% TMETN / 2.3% PMMA / 29.6% NP (5% coat) / 1.1% Be / 19% Beane (8)

<u>Isp</u>	<u>T_c</u>	<u>Density</u>
317 sec	3588°K	1.27 g/cc

33% P-BEP / 43% NP / 24% LMH-2 (Density 0.82 g/cc) (25)

<u>Isp</u>	<u>T_c</u>	<u>Density</u>
325 sec	3667°K	1.49 g/cc

63.5% Double Binder* / 17% AP / 19.5% LMH-2 (25)

<u>Isp</u>	<u>T_c</u>	<u>Density</u>
311 sec	3340°K	1.37 g/cc

1% NC / 62% NG / 1% TA / 2% NDPA / 2% Res.

NOTE: All level specific impulse values are at 1000 psia chamber pressure and reduced to 14.7 psia.

All vacuum specific impulse values are at 1000 psia chamber pressure and an expansion ratio of 40:1.

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XI. SOLID PROPELLANT THEORETICAL PERFORMANCE

(listed by oxidizer)

11.C

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AMMONIUM PERCHLORATE

25% TMETN / 4% DEGDN / 9.5% PNC / 1.5% TDI / 27.73% AP / 12.27% BE / 20% TAZ (25)

<u>Isp</u>	<u>T_c</u>	<u>Density</u>	<u>C*</u>
287 sec	3552°K	1.69 g/cc	5631 ft/sec

23.12% TMETN / 2.78% DEGDN / 8.79% NC / 1.85% TDI / 0.46% EC / 29.11% AP / 11.89% Be / 22% THA (25)

<u>Isp</u>	<u>T_c</u>	<u>Density</u>	<u>C*</u>	<u>Vac Isp</u>
293 sec	3485°K	1.628 g/cc	5650 ft/sec	332 sec

13% NC / 37% TMETN / 33% AP / 17% Be (8)

<u>Isp</u>	<u>T_c</u>	<u>Density</u>
280 sec	3965°K	1.66 g/cc

9.95% NC / 14.93% TMETN / 16.41% DEGDN / 1.0% TDI / 26.26% AP / 11.55% Be / 19.9% TAZ (8)

<u>Isp</u>	<u>T_c</u>	<u>Density</u>
289 sec	3481°K	1.62 g/cc

20% P-BEP / 55% AP / 25% LMH-2 (25)

<u>Isp</u>	<u>T_c</u>	<u>Density</u>	<u>C*</u>	<u>Vac Isp</u>
321 sec	3290°K	1.279 g/cc	6168 ft/sec	413 sec

10.8% NC / 3.9% DEGDN / 35.1% NIBTN / 35.2% AP / 15% LMH-2 (18)

<u>Isp</u>	<u>T_c</u>	<u>Density</u>
301 sec	3580°K	1.27 g/cc

NOTE:

All sea level specific impulse values are at 1000 psia chamber pressure expanded to 14.7 psia.

All vacuum specific impulse values are at 1000 psia chamber pressure and an expansion ratio of 40:1.

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11.4% NC / 23% TMETN / 22% Plasticizer / 27% AP / 3.2% Be / 13.5% LMH-2
(amorphous) (8)

<u>Isp</u>	<u>T_c</u>	<u>Density</u>
304 sec	3453°K	1.36 g/cc

63.5% Double Base Binder* / 17% AP / 19.5% LMH-2 (25)

<u>Isp</u>	<u>T_c</u>	<u>Density</u>
311 sec	3345°K	1.37 g/cc

*29% NC / 62% NG / 5% TA / 2% NDPA / 2% Res.

25% Binder (P-BEP/TVOPA :: 1/1) / 50% BTU / 20% AP / 5% Boron (25)

<u>Isp</u>	<u>T_c</u>	<u>Density</u>	<u>C*</u>	<u>Vac Isp</u>
297 sec	4255°K	1.828 g/cc	5940 ft/sec	366 sec

25% Binder (P-BEP/TMETN :: 1/1) / 60% BTU / 10% AP / 5% Boron (25)

<u>Isp</u>	<u>T_c</u>	<u>Density</u>	<u>C*</u>	<u>Vac Isp</u>
299 sec	4340°K	1.766 g/cc	5981 ft/sec	369 sec

70% P-BEP / 25% AP / 5% Boron (25)

<u>Isp</u>	<u>T_c</u>	<u>Density</u>	<u>C*</u>	<u>Vac Isp</u>
279 sec	3409°K	1.742 g/cc	5568 ft/sec	344 sec

NOTE:

All sea level specific impulse values are at 1000 psia chamber pressure expanded to 14.7 psia.

All vacuum specific impulse values are at 1000 psia chamber pressure and an expansion ratio of 40:1.

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NITRONIUM PERCHLORATE

20% PE / 65% NP / 15% A1

(25)

<u>Isp</u>	<u>T_c</u>	<u>Density</u>	<u>C*</u>	<u>Vac Isp</u>
281 sec	3870°K	1.772 g/cc	5526 ft/sec	355 sec

20% PE / 62.5% NP / 17.5% LMH-1

(25)

<u>Isp</u>	<u>T_c</u>	<u>Density</u>	<u>C*</u>	<u>Vac Isp</u>
292 sec	3527°K	1.616 g/cc	5781 ft/sec	361 sec

48% TMETN / 2.3% PMMA / 29.6% NP (5% coat) / 1.1% Be / 19% Beane

(8)

<u>Isp</u>	<u>T_c</u>	<u>Density</u>
317 sec	5388°K	1.27 g/cc

33% P-BEP / 43% NP / 24% LMH-2 (Density 0)

(25)

<u>Isp</u>	<u>T_c</u>	<u>Density</u>
352 sec	3667°K	1.49 g/cc

35% P-BEP / 40% BTU / 20% NP / 5% Boron

(25)

<u>Isp</u>	<u>T_c</u>	<u>Density</u>	<u>C*</u>	<u>Vac Isp</u>
300 sec	4408°K	1.807 g/cc	5951 ft/sec	374 sec

28.7% P-BEP / 14.4% NP / 11.7% LI / 45.2% BTU

(25)

<u>Isp</u>	<u>T_c</u>	<u>Density</u>
308 sec	4761°K	1.40 g/cc

75% NP (5% coat) / 25% POLYU

(25)

<u>Isp</u>	<u>T_c</u>	<u>C*</u>
270 sec	3518°K	5182 ft/sec

NOTE: All sea level specific impulse values are at 1000 psia chamber pressure expanded to 14.7 psia.

All vacuum specific impulse values are at 1000 psia chamber pressure and an expansion ratio of 40:1.

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HAP

20% PE / 65% HAP / 15% Al

(25)

<u>Isp</u>	<u>T_c</u>	<u>Density</u>	<u>C*</u>	<u>Vac Isp</u>
263 sec	2930°K	1.699 g/cc	5237 ft/sec	321 sec

20% PE / 55% HAP / 25% LMH-1

(25)

<u>Isp</u>	<u>T_c</u>	<u>Density</u>	<u>Vac Isp</u>
272 sec	2423°K	1.53 g/cc	343 sec

NOTE:

All sea level specific impulse values are at 1000 psia chamber pressure expanded to 14.7 psia.

All vacuum specific impulse values are at 1000 psia chamber pressure and an expansion ratio c. 40:1.

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INFO 635

15% NC / 30% TMETN / 1% AN / 44% INFO 635 / 10% A1

(25)

<u>Isp</u>	<u>T_c</u>	<u>Density</u>	<u>C*</u>
279 sec	3640°K	1.79 g/cc	5510 ft/sec

8% NC / 24% TEGDN / 50% INFO 635 / 18% LMH-1

<u>Isp</u>	<u>T_c</u>	<u>Density</u>	<u>C*</u>	<u>Vac Isp</u>
280 sec	3156°K	1.62 g/cc	5545 ft/sec	410 sec

NOTE:

All sea level specific impulse values are at 1000 psia chamber pressure expanded to 14.7 psia.

All vacuum specific impulse values are at 1000 psia chamber pressure and an expansion ratio of 40:1.

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XII. ABBREVIATIONS AND CODE NAMES

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ABBREVIATIONS AND CODE NAMES

<u>Symbol</u>	<u>Name</u>
Al	Aluminum
AN	Adiponitrile
AP	Ammonium perchlorate
Be	Beryllium
Beane	Beryllium hydride
BTU	Bis [Tris (Difluoramino) methyl] urea
DEGDN	Diethyleneglycoldinitrate
EC	Ethyl centralite
HAP	Hydroxylammonium perchlorate
INFO 635	[2-Tris (Difluoramino) methoxy] ethylammonium perchlorate
Li	Lithium
LMH-1	Aluminum hydride
LMH-2	Beryllium hydride
NC	Nitrocellulose
NDPA	2-Nitrodiphenylamine
NG	Nitroglycerin
NIBTN	Nitroisobutane trinitrate
NP	Nitronium perchlorate
P-BEP	Poly [1, 2-bis (difluoramino)] -2, 3-epoxy propane
PE	Polyethylene
PMMA	Polymethylmethacrylate
PNC	Polynitrocellulose
POLYU	Polyurethane
Res	Resorcinol
TA	Triacetin
TAZ	Triaminoguanadiniumazide
TDI	Toluene diisocyanate
TEGDN	Triethyleneglycol dinitrate
THA	TAZ • N ₂ H ₅ N ₃
TMETN	Trimethylolethane trinitrate
TVOPA	Tris [bis (difluoramino) vinoxyl] propane

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XIII. SOLID PROPELLANT DATA SOURCE LIST

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SOLID PROPELLANT DATA SOURCE LIST

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5. Callery Chemical Company
6. American Cyanamid Company
7. Dow Chemical Company
8. Atlantic Research Corporation
9. Aerojet-General Corporation
10. E. I. du Pont de Nemours & Company
11. Minnesota Mining and Manufacturing Company
12. Ethyl Corporation
13. Union Carbide Chemical Company
14. Chemical Engineering Handbook
15. Handbook of Chemistry and Physics
16. JANAF Compilation
17. United Technology Corporation
18. Lockheed Propulsion Company
19. Rocketdyne
20. Navy Propellant Plant
21. National Research Corporation
22. Thiokol Chemical Corporation
23. AFRPL (RPCL) - calculated
24. United Aircraft Corporation
25. AFRPL Computer Program

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(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)		
1. ORIGINATING ACTIVITY (Corporate author) Dept. of the Air Force AFSC, RTD Air Force Rocket Propulsion Laboratory, Edwards, Calif.		2a. REPORT SECURITY CLASSIFICATION Confidential
3. REPORT TITLE Propellant Handbook (U)		2b. GROUP 4
4. DESCRIPTIVE NOTES (Type of report and inclusive dates)		
5. AUTHOR(S) (Last name, first name, initial) von Doehren, Paul J., Lt, USAF		
6. REPORT DATE January 1966	7a. TOTAL NO. OF PAGES 135	7b. NO. OF REFS
8a. CONTRACT OR GRANT NO.	9a. ORIGINATOR'S REPORT NUMBER(S) AFRPL-TR-66-4	
b. PROJECT NO.	9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report)	
c.		
d.		
10. AVAILABILITY/LIMITATION NOTICES In addition to security requirements which must be met, this document is subject to special export controls and each transmittal to foreign governments or foreign nationals may be made only with prior approval of AFRPL-(RPC).		
11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY See Block 1	
13. ABSTRACT (U) A compilation of data on both liquid and solid propellants is presented with emphasis on liquids. Physical properties of liquids include: boiling point, freezing point, density, heat of formation, vapor pressure, critical properties, heat of vaporization, viscosity and specific heat. A discussion of the preparation method, toxicity, sensitivity, compatibility and availability of liquid propellants is also given. Property data on solid propellant components consists of densities and heats of formation. The results of theoretical calculations on the performance of both liquids and solids is presented and includes, when available and applicable, the maximum specific impulse, characteristic exhaust velocity, chamber temperature, mixture ratio, bulk density, maximum density impulse and mixture ratio, vacuum specific impulse and area ratio.		

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14	KEY WORDS	LINK A		LINK B		LINK C	
		ROLE	WT	ROLE	WT	ROLE	WT
	Rocket Chemical Propellants Propellants Handbook Liquid Propellants Solid Propellants						

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